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JOURNAL
OF THE
AMERICAN SOCIETY OF NAVAL ENGINEERS

VOL. 57. FEBRUARY 1945. No. 1.

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RECOMMENDATIONS FOR USING STEEL PIPING IN SALT WATER SYSTEMS.

BY PAUL FFIELD.*

INTRODUCTION.

The handling of salt water aboard ship has always been a problem of prime importance to the shipbuilder, and where the design has lacked the coordinated efforts of marine and corrosion engineers the results have sometimes been unfortunate. Salt water must be piped throughout a ship for many purposes. There must be an ample supply available at every quarter for emergency use in fire fighting. The nature of this service requires that the water be supplied at a high pressure. Salt water is also needed for sanitary purposes by both crew and passengers, and to complicate matters the Naval Architect may conceal this piping behind panelling for appearance sake. In

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addition, the marine engineer will need a reliable supply of salt water for the operation of main and auxiliary condensers, lubricating oil coolers and refrigerator units, and other machinery. Operating conditions may require that the water be handled hot and at high velocity to keep down the size and weight of pipe. Many marine engineering applications may operate 24 hours a day, and the shutdown of the plant because of piping failure can be serious. Even comparatively simple piping applications must be treated with respect. Salt water, unexpectedly leaking from a minor pipe, may effectively incapacitate vital electrically controlled equipment.

Reference to Appendix I indicates that the best materials for salt water systems are the copper nickel alloys and tin-wiped copper. The copper nickel alloys have good resistance to corrosion and fair anti-fouling properties. When these materials cannot be procured, or where a limited life expectancy can be tolerated, steel or iron, either black or galvanized, may be substituted, provided care is taken in the designing of the system to accommodate the higher corrosion rate of ferrous materials. The object of this discussion is to correlate some of the factors affecting corrosion rates and show how this information should be applied in order to obtain maximum service when iron or steel piping is used in salt water systems.

Types of Corrosion Affecting Iron and Steel.

When iron or steel* is used for a salt water system, it must withstand corrosion of two basic types:

(1) Corrosion resulting from the direct action of the salt water, i.e., the overall wasting away of the surface, and pitting resulting from solution cells or the velocity of the water.

(2) Galvanic Corrosion—an accelerated form of corrosion, which occurs when steel is connected to a more noble metal, such as bronze or brass.

An understanding of the factors affecting the rate of corrosion and proper care in the design and selection of materials will enable the engineer to keep corrosion at a minimum.

Corrosion Resulting from Direct Action of Salt Water.

Steel exposed to salt water corrodes at a fairly uniform rate. This rate is accelerated by: (1) increases in the rate of flow,

*Corrosion tests indicate that there is little to choose between wrought iron or steel. For the purpose of this discussion, the term steel will be considered to include the interchangeable use of either iron or steel.

(2) aeration of the salt water, and (3) increases in temperature. These accelerating influences can be evaluated with reasonable certainty and an appraisal of the probable life of steel piping is possible when the operating conditions are known.

Corrosion Rates in Still Water.

Corrosion tests indicate that iron or steel exposed to quiescent salt water corrodes at a rate of approximately .010 inch per year at normal sea water temperatures. This corrosion rate is approximate and is typical for a medium carbon steel exposed to salt water at Quincy, Mass., and Key West, Fla. At Baltimore, Md., Wilmington, N. C., and San Francisco, Cal., reported corrosion rates are only about one-half as much (.005 inch per year). If the steel is galvanized (2 ounce coating), the zinc coating will afford protection to the base metal for about one year at Quincy and Key West, and almost two years at the other locations.

Corrosion Rates in Flowing Water.

Water velocity accelerates the corrosion of steel pipe in several ways. It insures a continuous supply of salt water to the corroding area and washes away the products of corrosion, which might otherwise afford some protection to the metal underneath. At low velocities (up to about one foot per second) the corrosion rate is about the same as for quiescent salt water. At two feet per second and above, the corrosion rate increases with great rapidity. At the normal rates of flow encountered in marine engineering practice (5 to 10 feet per second), velocity may increase the corrosion rate of steel in salt water up to five times. This effect is shown in Figure 1. In practice, however, the corrosion rate often falls below its expected high level because adherent corrosion products and marine growths may form a barrier between the fast flowing salt water and the steel pipe, or the roughened surface of such deposits may slow down the boundary layer of water next to the pipe. This is also brought out in Figure 1, the upper curve showing the corrosion rate determined after exposure to flowing salt water for one week; the lower curve showing the corrosion rate of the same specimens after several weeks' exposure. For design purposes, the lower curve should be used when estimating the effect of flow on corrosion rate in salt water.

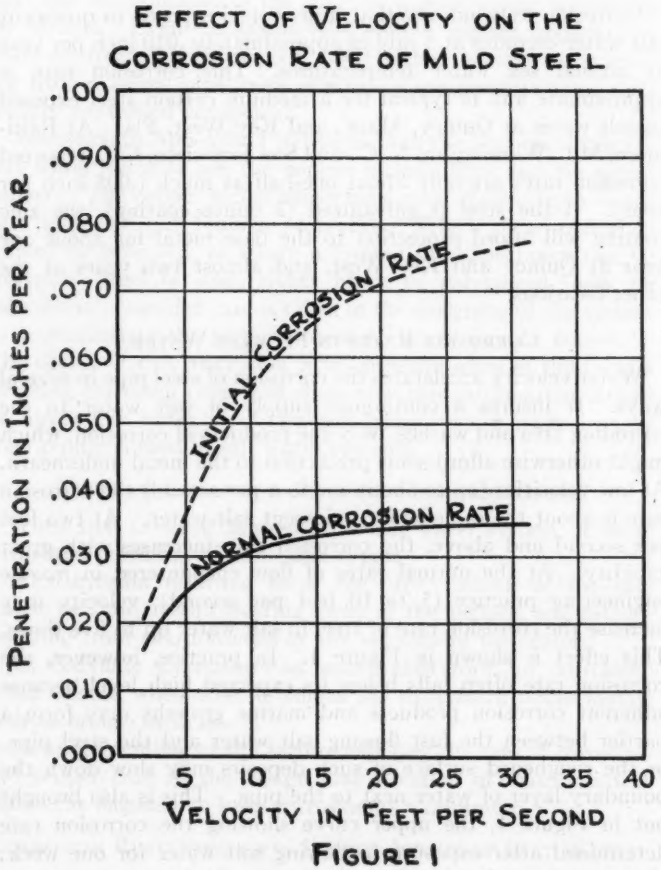

EFFECT OF VELOCITY ON THE
CORROSION RATE OF MILD STEEL
PENETRATION IN INCHES PER YEAR
.100
.090
.080
.070
.060
.050
.040
.030
.020
.010
.000
INITIAL CORROSION RATE
NORMAL CORROSION RATE
5
10
15
20
25
30
35
40
VELOCITY IN FEET PER SECOND

FIGURE 1

The operating conditions of each application should be analyzed. Many salt water systems are only used intermittently and a substantial reduction in the estimated corrosion rate can be made. A reduction of at least 50 per cent could be made in certain sanitary lines, lines of relief valves, lines servicing auxiliaries only in port, etc. Such lines may be subject to continuous corrosion by exposure to still water but corrosion is accelerated only when the water is flowing. For example, the piping to a crew's urinal and to the toilet in an officer's stateroom are both classified as sanitary piping. In the former case, the usual practice is to operate the flushing system of the urinal continuously for 24 hours per day, but in the latter case, the toilet may be flushed a few times daily, totalling not more than a few minutes flushing time.

Corrosion Rates in Aerated Water.

The amount of dissolved air or oxygen should be definitely considered a controlling factor in corrosion, particularly with ferrous pipe materials. In general, corrosion rates tend to increase proportionally with the supply of oxygen, primarily due to the fact that oxygen prevents cathodic polarization; the greater the oxygen supply, the greater the depolarizing effect. Areas of differential oxygen concentration likewise corrode at the point of oxygen deficiency: Thus, the more available oxygen, the greater the potentiality for corrosion.

Corrosion rates are further increased by entrained air and turbulence; the two conditions often going hand in hand. It is well known from experience in condenser tube service, that corrosion rates are greatly accelerated when the water carries entrained, as well as dissolved air. Impingement attack is an example of this type of corrosion. In such cases, water carrying entrained air and traveling at high velocities impinges on the metallic surface, resulting in pitting and eventually in perforation. Such attack becomes more serious when turbulence also is involved. Turbulent flow and medium sized bubbles appear to be most active in this respect. For these reasons, it is important in marine pipe design to keep aeration, entrained air, and turbulence at a minimum. This means care in selecting the location of sea chests so that they are not placed in the turbulent wake of an obstruction such as a bilge keel, and the elimination of sharp bends or other obstructions to flow in the piping systems.

Effect of Temperature on Corrosion Rates.

The corrosion rates for steel given in the preceding paragraphs apply to still and flowing salt water at an approximate temperature of 50 degrees F. However, the rate rapidly increases with temperature so that at 100 degrees F., corrosion would be approximately twice as active as at 50 degrees F. The use of steel in salt water systems at operating temperatures appreciably above 110 degrees F. is not recommended, particularly if the water velocity is high.

Reliability of Corrosion Rate Estimates.

The above estimates of corrosion rates are all approximate. However, they are sufficiently accurate so that the curves shown in Figure 1 can be used by the designing engineer in determining the life expectancy of pipe when service conditions can be evaluated.

Correlation of Corrosion Rates and Design.

In designing salt water systems, the engineer should first estimate the temperature and velocity of the salt water to be carried. If these accelerating influences indicate a high rate of corrosion, consideration should be given to the use of materials other than steel. Alternatively, it may be possible for the engineer to reduce the accelerating influences somewhat by modifications in design such as a change in pipe size, without seriously impairing the efficiency of the system. He may even tolerate reasonably high corrosion rates when they occur in localized sections of piping which are readily replaceable. With these considerations in mind, the engineer can estimate whether or not the service life will be acceptable.

Galvanic Corrosion.

The corrosion discussed in the previous paragraphs is inherent in the nature of the materials and the conditions under which they must operate. It can sometimes be reduced, but not eliminated, by modifications in design. With the exception of galvanizing, the application of protective coatings is not generally practicable, and even galvanizing offers only temporary protection.

Corrosion resulting from association with dissimilar metals (galvanic corrosion) presents an entirely different problem to the

engineer, since he can almost completely control it. But full advantage of this control can be secured only when its mechanism is understood.

Mechanism of Galvanic Corrosion.

When dissimilar metals are connected together in an electrolyte, a battery effect is created, resulting in a flow of electric current from one metal, through the electrolyte, to the other metal. The metal discharging the current is called the anode, while the metal receiving the current is known as the cathode. The current leaves the anode in the form of electrically charged particles of that metal*, the charges of which are received by the cathode. This results in the disintegration of the anode, and the protection of the cathode. Thus, galvanic corrosion is corrosion resulting at the anodic metal when dissimilar metals are connected together in an electrolyte, such as sea water. It is distinct from the simple corrosion occurring when an uncoupled metal is exposed to salt water, and is far more active.

Steel is anodic to most metals which possess good resistance to salt water. Large components of valves, strainers, manifolds, etc., are often made of brass, bronze, and monel metal, all of which are cathodic to steel, and these metals cause accelerated galvanic corrosion when in contact with steel in salt water.

Current-Flow Factors in Galvanic Corrosion.

Control of galvanic corrosion is obtained by any means which retards or stops the flow of current from the anode. As far as the marine engineer is concerned, the principal factors controlling the flow of current between dissimilar metals are:

(1) the potential difference between the metals,
(2) the relative areas of the metals exposed,
(3) the conductivity of the electrolyte,
(4) the resistance of the electrical connection between the dissimilar metals, and
(5) the proximity of the two metals.

The influence of these individual factors may be summarized as follows:

*When metal atoms dissolve in water, they lose one of their negative charges (electrons) and thus become positively charged atoms. When atoms are in this electrically unstable state they are called "ions", from the Greek word meaning traveler, since they must seek electrical charges to restore their equilibrium.

Potential Difference between Anode and Cathode.

The factor usually given prime consideration, sometimes to the exclusion of the others, is the selection of materials of least potential difference. Some metals in the electro-chemical series are so closely related that there is but little tendency for current flow and they can be used in contact without significant corrosion. Table I shows typical alloys used in marine engineering, grouped in the order of their tendency to corrode galvanically.

TABLE I.

Corroded End (Anodic) Zinc
Steel—Iron. Cast steel, malleable iron and low alloy steels and irons (2 per cent max. alloy)
Lead, tin
Muntz metal, manganese bronze, tobin bronze, naval brass
Yellow brass, red brass admiralty metal, copper, silicon bronze, 70-30 copper nickle, composition G or M bronze, hydraulic bronze
Monel metal
Protected End (Cathodic)

Materials within a group in the above list can be used in contact with each other; other combinations, however, can cause appreciable galvanic corrosion. Example:—In a system made from copper nickel pipe, satisfactory service will be obtained if fittings are made from Composition G or M bronze. But if steel were substituted for the copper nickel pipe, active galvanic corrosion of the steel would result. Thus, the first step of the designing engineer should be to determine the potential relationships of the materials he proposes to use. But while it is true that galvanic corrosion is controlled by the potential difference between the metals involved, full consideration must be given to the other determining factors.

Relative Areas of Anode and Cathode.

It is not always realized that the rate of galvanic corrosion is roughly proportional to the relative areas of the coupled materials. If we postulate two different metals of unit surface area, connected and immersed in an electrolyte, one becomes cathodic, the other anodic, and a markedly accelerated corrosion rate occurs at the anode. If the surface area of the cathode is increased ten times, and the anodic area remains the same, the cathodic surface then has ten times the potentiality for attracting electrons from the anode. Theoretically, the current flow is increased to ten times its former rate, (actually to something less than the theoretical value). This markedly increased current, concentrating on the original unit area of anode, steps up the corrosion rate of the anode by a similar order of magnitude. In like manner, decreasing the cathodic area proportionately reduces its ability to attract electrons, and correspondingly decreases the corrosion rate of the anode.

In actual practice, the behavior of anodic materials coupled to cathodic materials is controlled in large part by this factor of relative areas. Thus, large cathodic areas should not be connected to relatively small anodic areas because such combinations will cause severe corrosion at the anode. By contrast, relatively small cathodic areas exert an insignificant influence on the corrosion rate of the anode. Steel valves with bronze trim are an example of the judicious application of this principle. There is an appreciable potential difference between bronze and steel (See Table I), but the relatively small area of cathodic bronze trim is impotent to cause a significant increase in the corrosion rate of the anodic steel valve body.

Advantage can be taken of the effect of dissimilar areas when it is realized that the area of the cathode need not literally be reduced. It can effectively be reduced as far as corrosion is concerned, by reducing the exposed area with an application of paint. The paint surface need not be perfect since pinholes represent an insufficient area of cathode to produce significant galvanic corrosion at the anode. The natural impulse would, of course, be to paint the anodic surface to stop it corroding. However, no paint film is completely devoid of pinholes and the area exposed by such pinholes would represent an unfavorable ratio of relative areas and extremely rapid localized corrosion would result.

Conductivity of the Electrolyte.

The function of the electrolyte is to act as a carrier for the flow of current from the anode to the cathode. The greater the ability of the electrolyte to carry the current, the greater the potentiality for galvanic corrosion. Impurities in water can increase the efficiency of water as an electrolyte, particularly dissolved metallic salts such as those found in sea water. Thus, salt water is far more potent than fresh water as an electrolyte

Circuit Resistance.

In addition to the resistance of the electrolyte, current flow depends on the resistance of the remainder of the electrical circuit. If the resistance is infinite, that is, the materials are insulated, then no galvanic corrosion occurs at the anode. Any condition that increases the resistance of the circuit, such as paint on the contacting surfaces, tends to reduce the degree of galvanic corrosion.

Proximity of Anode and Cathode.

In most cases, dissimilar surfaces must be fairly close together to suffer galvanic attack. This is particularly true with electrolytes of poor conductivity, and in such cases, the corrosion will be found close to the junction of the metals. With electrolytes of good conductivity, such as sea water, the attack may be found at points considerably distant from the junction.

Designing to Minimize Galvanic Corrosion.

With an understanding of the factors affecting galvanic corrosion, it is possible to design piping systems to eliminate or minimize it. Each of the following precautions should be considered by the marine engineer:

Eliminate the Electrolyte.

In a salt water system, this sounds like a paradox. However, many salt water systems are used intermittently, and if such systems automatically drain the salt water from contact with dissimilar metals during periods of disuse, galvanic corrosion will occur only when they are operating, and the cumulative corrosion may then be acceptable. For example, a bronze

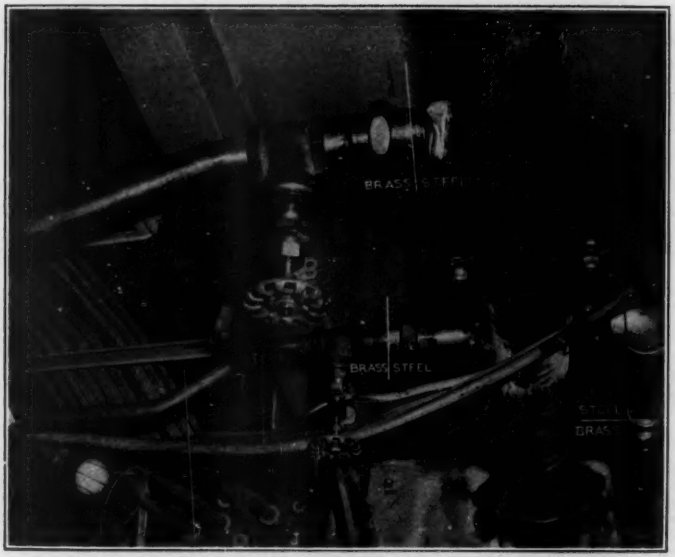


FIGURE 2.—Branch at top left will fail prematurely at threaded nipple. Branch at lower left will probably fail prematurely at threaded coupling. Branch at right will fail in threads of waster. These branches were not installed according to plan which called for brazed joints in accordance with Figure 1b in Appendix 2.

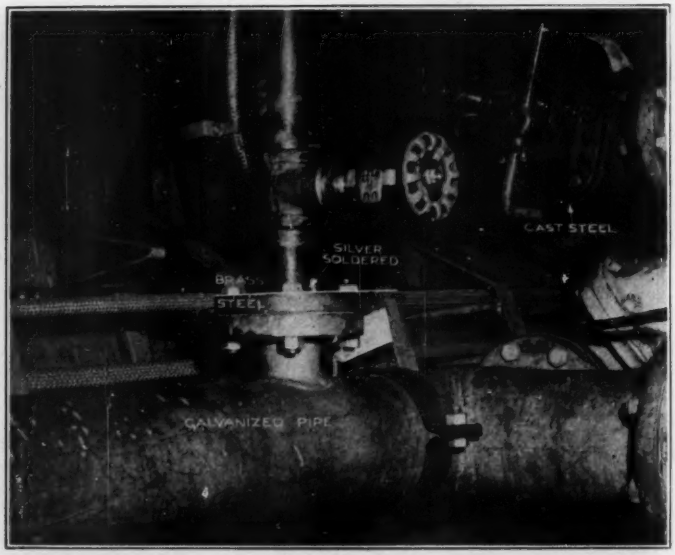


FIGURE 3.—Good design gives trouble free service. Large valve at right is bronze mounted cast steel. Small brass branch line in center, is silver soldered to oversized steel flange and branch connection consists of short length of oversize pipe. The brass to steel ratio favors the latter and the steel branch pipe is large enough to avoid clogging with corrosion products. There are no threaded joints to give trouble.

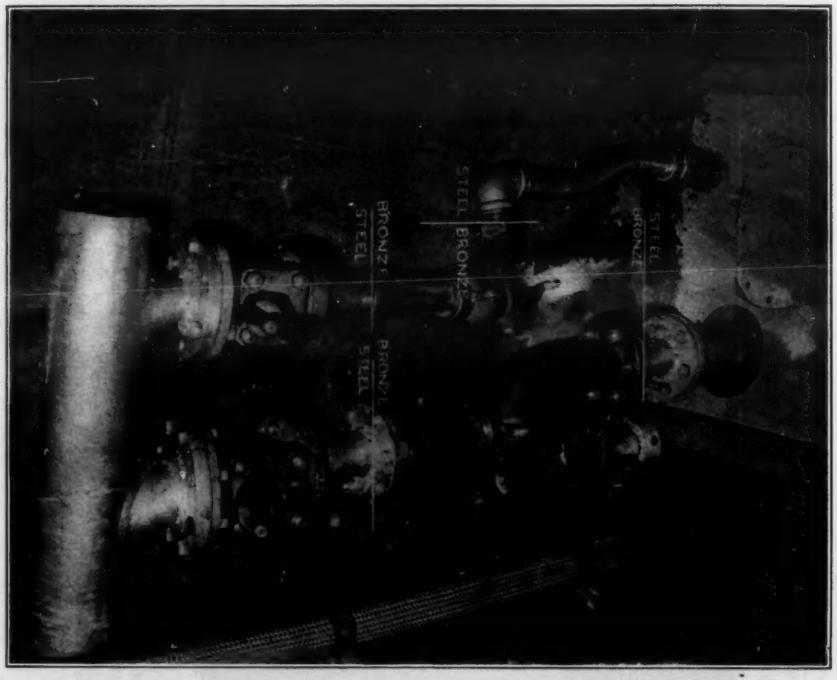


FIGURE 4—The large bronze eductor on the right is properly connected to the steel system with two galvanized waster pieces. But during the conversion of this vessel a second eductor was installed without consideration of the original instructions. The smaller eductor will in all probability give trouble at the threaded nipple.

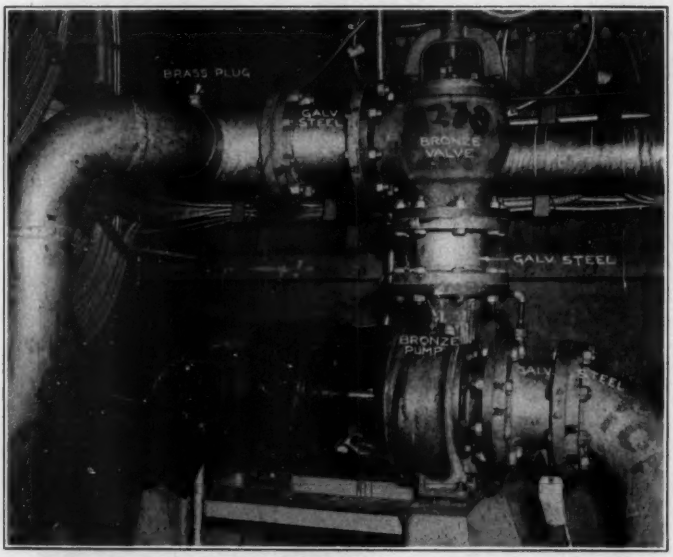


FIGURE 5.—The bronze housing of the air cooler circulating water pump and the bronze globe valve should have been connected with a cast bronze or tinned copper filler piece instead of the galvanized waster. The wasters at top left and lower right are too short and not in accordance with the plan which calls for 12 inches. The brass plug screwed in the welded boss can be expected to leak but no serious damage to the pipe will occur.

eductor installed in a steel line for scavenging bilges is in direct contact with bilgewater and salt water during operating periods. Continual galvanic corrosion of the steel can be avoided if the eductor is arranged to be self-draining when not operating. Thus, by eliminating the electrolyte from the coupled metals, it is possible to reduce galvanic corrosion to an acceptable rate. Another example is found in a threaded connection between steel and brass. The screw thread not only reduces the wall thickness of the metal, but it also permits salt water to seep between the threads in the joint. When this happens, rapid galvanic corrosion of the threads results and failure of such a joint may be expected in about three to six months (Figure 2). The trouble can be averted by eliminating the electrolyte from the joint, i.e., by replacing the threaded joint with a brazed or silver soldered socket joint. When properly brazed, no water can enter the joint between the dissimilar metals, hence no galvanic corrosion can occur, (Figure 3).

Select Materials of Least Potential Difference.

In a steel salt water system, if fittings are available in brass or steel, it is preferable to use steel. If it is not possible to avoid dissimilar metals, only those from within a group or from adjacent groups (Table 1), should be selected, unless the following additional precautions are taken to minimize galvanic corrosion:

Decrease the Area of the Cathode Relative to the Anode.

In the event that it becomes necessary to couple dissimilar metals under circumstances where galvanic corrosion will result, it is highly important that every effort be made to make the anodic area as large as possible with respect to that of the cathode, (Figure 3). This can be done in one of two ways, either by designing such couples to be predominant in anodic surface area (See Appendix II), or by reducing the effective cathodic area as much as possible by the application of suitable protective coatings, like paint, plastics, etc. It should be remembered that this latter method is effective only as long as the coating remains intact, or reasonably so.*

*One electrochemical effect of galvanic corrosion is to create an alkaline zone surrounding the cathode. This makes the painting of the cathode a serious problem because the alkaline reaction tends to destroy the adhesion of the paint and promotes blistering. Development of suitable protective coatings for cathodes is now under way. Preliminary indications are that sprayed thiokol is particularly effective, and is little affected by the alkaline effect at the cathode

Insulate or Separate Dissimilar Metals.

In many cases, galvanic corrosion can be eliminated if dissimilar metals are insulated from each other, preventing the flow of electric current between them. Sleeves, gaskets, bushings, and washers made from rubber, mica, plastics or other insulating materials are good examples of circuit breakers. It is well to appreciate that brackets, valve operating gear, foundations, etc., may also have to be insulated to prevent the completion of the electrical circuit.

Experience indicates that even if long "insulating" sleeves are not effective insulators, they are none-the-less effective in that they lengthen the distance between the anode and cathode, thus increasing the resistance of the circuit. In spite of the good electrical conductivity of salt water, there is apparently some proximity effect and it is always desirable to separate dissimilar metals as much as practicable.

Use "Waster Pipes".

Even when the many factors discussed previously are given full consideration, it may be necessary to directly couple dissimilar metals and localized corrosion may result. Should this be the case, it is good practice to insert "waster pipes" between the two metals. As the name implies, "waster pipes" are short lengths of expendable pipe inserted in way of the areas of expected corrosion.

All waster pipes should be galvanized steel, standardized as to dimensions and designed for easy removal. They should, furthermore, be of the heaviest wall thickness available, have a minimum length of six diameters, or 12 inches, and 100 per cent replacements should be provided, (Figure 4). It is desirable to make the diameter of the waster piece as large as possible, to obtain a favorable balance between relative area of steel anode to non-ferrous cathode. Figure 2F, in Appendix II, is an example of this principle. Wasters can sometimes be dispensed with altogether, if the non-ferrous line is connected directly to a large diameter steel pipe, because of the resulting favorable ratio of areas. Figure 1A, in Appendix II, is an example of this practice. Figure 5 illustrates the mis-use of wasters—the result of an engineer's over-enthusiasm in the conservation of critical materials.

Pipe Fouling by Corrosion Products.

Under conditions of low water velocity, the corrosion products of steel may build up to a thickness of ¼ inch or more. This is not serious in large diameter pipe but, in a ½ inch line, they might readily choke off the water supply. The only feasible solution to the problem is to use a more corrosion-resistant alloy, such as light wall 70-30 copper nickel tubing. The brasses have been used with moderate success but pipe, rather than tube, must be specified, because pitting by flowing salt water is certain to occur. Since the tendency to corrode is enhanced at galvanic couples, the adjacent steel pipe should be made as large in diameter as possible (See Figures 1A and 2F, Appendix II).

Fouling by Marine Growths.

Marine growths adhere to some metals and alloys, while others possess anti-fouling properties. Appendix I, shows that, in general, copper alloys have good anti-fouling properties, while steel is poor in this respect. Galvanizing affords some anti-fouling protection but this is only temporary.

The extent of fouling by marine growths depends on many things. In the first place, it occurs only in shallow water, and is unlikely to occur even near the surface in water deeper than 100 feet. Unfortunately, however, a ship may become inoculated with the organisms in shallow water and their growth will continue in deep water. Temperature is important. Fouling is most serious in tropical waters, somewhat less severe in temperate waters between late spring and early fall, and only moderate in cold waters. Reports show that fouling increases rapidly with temperature up to about 90 degrees F., then falls off and above 100 degrees F. is practically eliminated. Fouling is more severe in stagnant water, but it can readily occur in water traveling at velocities up to 5 feet per second, wherever eddies give the organism sufficient time to adhere. Once attached to the pipe, additional eddies are set up, permitting the growth to progress. Marine organisms require oxygen, therefore, fouling is most extensive where the oxygen supply is the greatest.

The galvanic behavior between dissimilar metals may also affect the fouling properties of a metal. It is important to realize that while galvanic corrosion causes deterioration of the

anode, the nature of the process results in the cathode being protected. Most marine engineers are familiar with this phenomenon, and zincs which are anodic to steel are often used in way of bronze for such protective purposes. Numerous tests show that copper is anti-fouling only as long as it is corroding. Connected to a less noble metal, it is galvanically protected, the corrosion rate becomes very low, and the copper loses its anti-fouling properties.

The above summary gives the marine engineer some idea relative to the extent of fouling that may occur in piping systems. It is important, therefore, that some consideration be given to the factors that control marine growths. In the event that the designer is unable to use copper alloys in the piping system, it is necessary that he determine which lines operate under conditions which promote fouling. An example would be a fire main used for sanitary purposes. Here, the water requirements insure a supply of oxygen conducive to fouling, and an insufficient velocity to suppress the tendency to foul. In such lines, the designer should make provision for cleaning out the line by installing clean-out plugs at strategic locations.

Effectiveness of Corrosion Precautions.

In a class of more than 100 vessels built by the Bethlehem Steel Company, W.P.B. restrictions forced the use of substitute materials in lieu of copper-nickel alloy for the salt water lines. Steel was used for all lines 2 inches and above. The precautions necessary to avoid galvanic corrosion were summarized in a simple "do" or "do not" instruction sheet for designers, (Appendix II). Loose phraseology was deliberately avoided because designers should not be called upon to do the "corrosion thinking". Instructions were given freely to all draftsmen and pipe shop personnel to promote the cooperation of all hands. Results have been most gratifying. To date, as far as we can determine, there have been no failures of steel piping in these vessels, the first of which was launched January 9, 1943. It is confidently expected that when failures do occur, there will be isolated instances where the instructions were not followed, (see Figures 2 and 4). The author inspected the first vessel after about 12 months' operation in semi-tropical waters. Nineteen lines were opened for examination, and in only one was there appreciable corrosion. This was in the form of pits which may be

traceable to an unusual operating condition. By contrast, other vessels using the same materials, but without the benefit of these precautions, gave a great deal of trouble after a few months' service.

Experience would indicate that the precautions given in Appendix II are ample. The minimum size of 2 inches for steel pipe has been proven conservative and it would appear as though this limit could safely be dropped so that all pipes 1 inch IPS and lower would be copper alloy.

The precautions were developed at a time when copper-nickel tubing was not available and red brass was reluctantly substituted for the small pipes. There have been a number of failures of this small brass piping and it is recommended that the instructions be modified to call for copper-nickel for pipe 1 inch IPS and less, if this material is available.

The author wishes to acknowledge the assistance of L. M. Mosher who conducted the laboratory tests.

APPENDIX I.

Comparison of Salt Water Piping Materials Issued to Design Department Bethlehem Steel Company Shipbuilding Division.

PROPERTIES OF MATERIALS USED FOR SALT WATER PIPING SERVICE.

Material	Resistance to Corrosion						Recommended Max. Velocity ft/sec. (1)	Resistance to Marine Fouling
	General Surface Attack		Local Pitting (1)		Galvanic Corrosion when Connected to Bronze	Dezincification (3)		
	Flowing	Stagnant(2)	Flowing	Stagnant(2)				
Copper	Good	Bad	Very Bad	Bad	Good	Immune	5 (1)	Excellent
Copper Tin Dipped	Fair	Bad	Very Bad	Bad	Good	Immune	5 (1)	Fair
Copper Tin Wiped	Excellent	Excellent	Excellent	Excellent	Good	Immune	8	Fair
Red Brass 85-15	Good	Good	Bad	Bad	Good	Practically Immune	5 (1)	Good
Yellow Brass 70-30	Good	Fair	Bad	Bad	Fair	Very Susceptible	3 (1)	Good
Admiralty 70-29-1	Good	Fair	Fair	Bad	Fair	Susceptible	5 (1)	Good
Iron or Steel Galvanized (4)	Bad (5)	Good	Fair	Good	Bad (6)	Immune	20 (7)	Fair (8)
Copper Nickel 70-30	Excellent	Excellent	Excellent	Good	Good	Immune	20	Fair
Nickel Copper Monel	Excellent	Bad	Excellent	Bad	Good	Immune	50	Bad

(1) Local pitting may occur in regions of disturbed flow even at moderate computed velocities.
"Very bad" indicates probability of this type of corrosion.
"Bad" indicates probability, but material has somewhat more resistance thus reducing the frequency of this type of corrosion in a piping system.
"Fair" indicates the possibility of this type of corrosion.
"Good" indicates that this type of corrosion seldom occurs at normal velocities.
"Excellent" indicates that this type of corrosion will not occur with normal velocities.
In using materials rated as bad it should be remembered that it is difficult to avoid pitting conditions (regions of disturbed flow) in the design and layout of a piping system.

(2) "Stagnant" applies to lines where flow of salt water may not occur for protracted periods such as some sections of firemains, gauge lines, etc.

(3) Becomes serious in hot systems. Dezincification of brass is sure to follow galvanic corrosion, therefore consider susceptibility to galvanic corrosion as well.

(4) Galvanizing adds about one year to pipe life at velocities below 2 ft. sec. Above this velocity, corrosion rate increases so that at 6 ft. sec. the increased life due to galvanizing is only about three months.

(5) The corrosion rate is high but it can be predicted with reasonable certainty. Contact Materials Engineer for estimate.

(6) Galvanic effect can be reduced or eliminated by care in design and selection of adjoining materials. See "Precautions to be Taken in the Design of Iron or Steel Pipe" by Paul Ffield, October 15, 1942.

(7) Any velocity over 1 ft. sec. increases the corrosion rate of iron, reaching a high rate (about .040 inch per year at 50 degrees F.) at 6 ft. sec. above this velocity there is little further increase. Corrosion rate at 110 degrees F. for a given velocity will be double the rate at 50 degrees F.

(8) Zinc has moderate anti-fouling properties; when zinc is lost piping will foul with marine growths as well as with rust.

Paul Ffield, Materials Engineer, Nov. 5, 1942.

APPENDIX II.

Instructions Issued to the Design Section of Bethlehem Steel Company Shipbuilding Division.

"Precautions to be Used in the Design of Iron or Steel Pipe Salt Water Systems."

PRECAUTIONS TO BE TAKEN IN THE DESIGN OF IRON OR STEEL PIPE SALT WATER SYSTEM.

In salt water systems iron or steel (hereinafter referred to as steel) piping differs from copper or brass in that it corrodes much faster and is subject to fouling. However, it can give satisfactory service over a limited period. The following precautions will contribute to maximum life.

Selection of Pipe Size and Material for Continuously Wet Operation

The life of steel pipe is limited, therefore design for easy replacement.

All piping must be galvanized.

All cold salt water piping below 4 inches must be extra heavy.

All hot salt water piping (110 degrees F. max.) must be extra heavy.

For salt water piping operating above 110 degrees F. consult Materials Engr.

All steel piping fouls with rust deposits: Use largest I.D. practicable.

For the above reason never specify steel piping in sizes 1½ inches or below.

Selection of Pipe Size and Material for Wet-Dry Operation

Use standard size galvanized pipe where service is mostly dry: example dry pipe in sprinkler system. Consult Materials Engr. before specifying standard pipe (below 4 inches) in other wet-dry services.

Instructions to Avoid Fouling

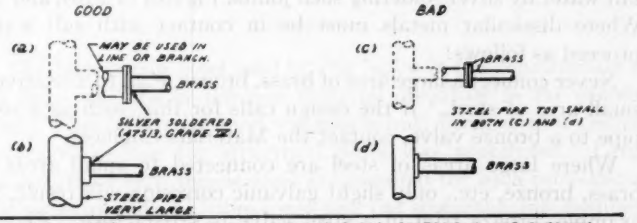
All steel pipe will foul with rust or may foul with marine growths therefore locate flanged joints to facilitate dissembly and cleaning, particularly where pipe is adjacent to bronze, brass, copper, etc. Figures (a) and (f).

Instructions to Avoid Galvanic Corrosion

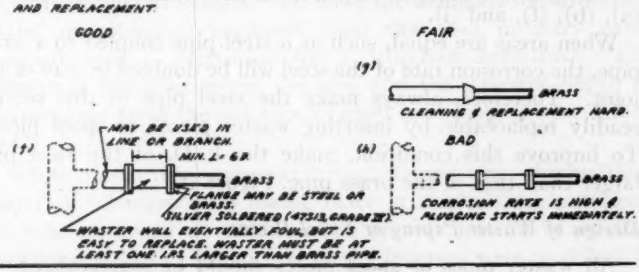
Galvanic corrosion will occur where steel piping in salt water service is connected to bronze, brass, copper, monel, etc. Therefore, avoid dissimilar metals in the system if possible, for example,

DESIGNING CONNECTIONS BETWEEN BRASS AND STEEL PIPE

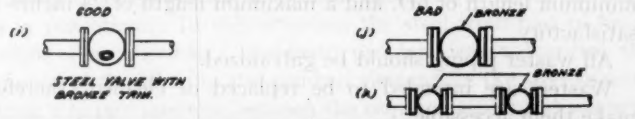
1. WHEN DIA OF STEEL IS AT LEAST TWICE THE DIA OF BRASS NO WASTER IS NECESSARY.



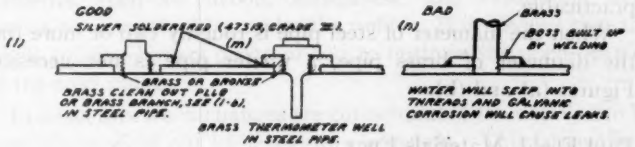
2. MAKE WASTER AS LARGE IN DIA AS POSSIBLE AND ACCESSIBLE FOR CLEANING AND REPLACEMENT.



3. NEVER CONNECT LARGE AREAS OF BRASS WITH STEEL.



4. ALL JOINTS BETWEEN BRASS & STEEL MUST BE SILVER SOLDERED. DO NOT SCREW BRASS INTO STEEL FITTINGS OR VICE VERSA.


GOOD
SILVER SOLDERED (47S13, GRADE III).
(l)
(m)
BRASS OR BRONZE
BRASS CLEAN OUT PLUG OR BRASS BRANCH, SEE (l-b), IN STEEL PIPE.
BRASS THERMOMETER WELL IN STEEL PIPE.
BAD
(n)
BRASS
BOSS BUILT UP BY WELDING
WATER WILL SEEP INTO THREADS AND GALVANIC CORROSION WILL CAUSE LEAKS.

select steel, cast iron or malleable fittings in preference to bronze. Alternatively, eliminate the salt water. For example, a bronze eductor in a steel line can be arranged to be self-draining when not operating and galvanic corrosion can only occur during the short operating periods. Another example is a brass pipe screwed in a steel flange, salt water will seep in the screwed joint causing corrosion and leakage. Therefore, exclude the entry of salt water by silver soldering such joints. Figures (a), (b), and (i). Where dissimilar metals must be in contact with salt water proceed as follows:

Never connect a large area of brass, bronze, etc., to a relatively small area of steel. If the design calls for this, such as a steel pipe to a bronze valve, contact the Materials Engineer.

Where large areas of steel are connected to small areas of brass, bronze, etc., only slight galvanic corrosion will result, for example, bronze trim in a steel valve is satisfactory. Figures (a), (b), (f), and (i).

When areas are equal, such as a steel pipe coupled to a brass pipe, the corrosion rate of the steel will be doubled in way of the joint. Therefore, always make the steel pipe in this section readily replaceable by inserting waster pieces or spool pieces. To improve this condition, make the I. D. of the steel pipe larger than that of the brass pipe. Figure (f).

Design of Waster Piping or Spool Pieces

All waster pipes or spool pieces should be standardized. A minimum length of 6D. and a maximum length of 24 inches are satisfactory.

All waster piping should be galvanized.

Wasters are intended to be replaced or cleaned; therefore, make them accessible.

For longer life, make waster piping as large in diameter as practicable.

When the diameter of steel pipe is roughly two or more times the diameter of brass pipe, a waster pipe is not necessary. Figures (a) and (b).

Paul Ffield, Materials Engr.
10–26–42 (Revised)

THE APPLICATION OF STATISTICAL METHODS TO THE DEVELOPMENT AND QUALITY—CONTROL OF HIGH TENSILE STEEL.

By Charles M. Mottley, Lieutenant, U.S.N.R., Member.

The high tensile steel used by the Navy in the construction of its ships was one of the first material casualties in the present war. This steel contained vanadium but, because of a critical shortage, its use for structural plate was prohibited. Large quantities of high tensile steel are required for such purposes as the pressure hulls of submarines and the strengthening members of surface combat vessels. To meet the demands for structural plate, metallurgical engineers from the steel industry came forward with a suggestion for a titanium substitute. The Bureau of Ships approved the idea and the industry began to change over from the old type of steel to the new in the fall of 1942.

While casualties were occurring among the shipbuilding materials, changes were taking place in shipbuilding practices. In order to speed up production a greater amount of welding was done; a higher proportion of the laborers were unskilled in welding techniques; and inspection could never be as thorough as in peacetime. In this situation the steel itself had to be as foolproof as possible. The main problem was to control the amount of the alloying and residual elements in the steel so as to strike a happy medium between the required structural strength and weldability. Too high a quantity of certain hardening elements, such as carbon, manganese, and chromium, were known to cause cracking under the welds. It is obvious that the whole quality-control program had to begin in the open-hearths of the steel plants.

In peacetime when changes are contemplated the details can be carefully worked out by laboratory research. This is usually a time-consuming procedure and always carries with it the hazard of applying laboratory results to production conditions. In the emergency immediate, decisive action was needed. With no

time available for preliminary investigations, reliable knowledge, as a basis for action, had to be produced on the job. Research and development, and quality control, therefore, had to go hand in hand with production.

History of the Development.

The first job was to set up specifications for the strength, ductility and welding requirements of the new steel based on previous experience with the old vanadium steel. The representatives of the industry pooled their information on possible production methods to produce steel of the required quality. Experimental heats of the titanium steel were made and plates were sent to a Navy test laboratory to determine the ability of each producer to supply material of the desired quality. As a result of the tests, about ten different plants were judged to be qualified. Then, as production started, the major deficiencies in practice were cleared up and the industry changed over rapidly from the old steel to the new.

From time to time representative shapes and half-inch plates were selected from the run-of-the-mill production, and were sent to the Industrial Test Laboratory at the Navy Yard, Philadelphia. There the samples were subjected to chemical, physical and welding tests under essentially the same laboratory conditions. These tests have come to be known as product and process quality tests. Information was rapidly accumulated on the chemical composition, the physical properties and the weldability of the steel. The data were analyzed statistically, using the most up-to-date methods, in order to obtain as much information as possible. The results of the analysis were then used to make constructive suggestions to the producers who voluntarily improved the quality of the steel by making the necessary changes in the production process.

Early in 1944 the supply of vanadium increased to such an extent that its use for structural plate was again permitted. However, the knowledge gained during the emergency period indicated that a greatly improved steel could be produced. Instead of returning entirely to the old specification, a new high tensile steel with superior welding qualities has now been specified. This new steel has been produced in quantity since June, 1944. It not only surpasses the old vanadium steel in its

uniform quality but it requires only one-third of the amount of the alloy, thus reducing the cost.

The unique feature of the whole program was the establishment by the Bureau of Ships of a quality-control unit which used modern methods of statistical analysis for handling the large mass of complicated data. Through the use of these techniques the data were reduced to a form in which the exact problems could be identified, pertinent relationships could be readily discerned, and a sound basis could be established for initiating effective action by the industry.

It is appropriate at the outset to describe briefly how the group that handled the situation was organized. The statistical unit was functioning as the result of the vision of two practical naval engineers. Captain Lybrand P. Smith, U.S.N. (ret.) and Howard F. Smith, mechanical engineer, (now Captain, U.S.M.C.) had already done a considerable amount of pioneering work in the application of statistical methods to the Bureau's problems. Their insight and published reports showed that many of the situations which were encountered in the construction, operation and maintenance of naval vessels were so characterized by variability that statistical methods of analysis were essential, if sound conclusions were to be reached. As a result of their efforts a statistical unit (now a Sub-section of the Research and Standards Branch) was established by the Bureau of Ships in 1942, to analyze engineering research data. Personnel with professional training in mathematical and applied statistics were obtained for the work.

When the complexity of the high tensile steel situation became apparent Captain H. A. Ingram, (then Head of the Research and Standards Section), set up a cooperative arrangement whereby the statistical unit assisted the metallurgical group, and thus the quality-control unit came into being. It soon became evident that in order to get the best results, definite liaison should be established with the producers. Accordingly, beginning in September, 1943, periodic meetings were arranged with their representatives, who acted through the Plate Committee of the American Iron and Steel Institute. The various agencies cooperated in a whole-hearted manner and a free exchange of information between the Navy and the industry resulted. Whenever difficulties arose the pertinent data were assembled and presented to the particular producer concerned. In every

UNITED STATES NAVY YARD
PHILADELPHIA, PA.

REPORT No.....

REPORT OF TEST

CONTROL SAMPLE

TITANIUM TREATED MANGANESE HIGH TENSILE STEEL

NAVY DEPT. SPEC. 4836

MANUFACTURER..... PLANT.....

HEAT No..... CONTRACT No.....

SAMPLE RECEIVED.....

CHEMICAL COMPOSITION

C.	Mn.	P.	S.	Si.	Cu.	Cr.	Ni.	Mo.	Ti.	Va.	

TENSILE PROPERTIES

TREATMENT	DIRECTION	TENSILE STRENGTH P.S.I.	YIELD POINT P.S.I.	ELONG. % IN 8"	REDUCTION OF AREA
As Received	Longitudinal				
As Received	Longitudinal				
As Received	Transverse				
As Received	Transverse				
Normalized	Longitudinal				
Normalized	Longitudinal				
Normalized	Transverse				
Normalized	Transverse				

TEE BEND PROPERTIES

ANGLE AT MAX. LOAD	MAXIMUM LOAD PER INCH WIDTH	ANGLE OF BEND	FRACTURE

BRINELL HARDNESS..... NICK BREAK.....

.....
METALLURGIST

FIGURE 1. SAMPLE DATA SHEET SHOWING THE ITEMS REPORTED

case the difficulties were cleared up by getting at the facts themselves. The whole program was remarkable for the effective producer-consumer relations. The method employed for handling the program is now serving as a model for the development and quality control of other shipbuilding materials.

At the peak of the shipbuilding program, in the early part of 1944, about 10,000 tons of high tensile steel of the manganese-titanium type were being purchased each month. Since so much of this steel has been used in a variety of combat vessels, its characteristics should be of considerable interest to many engineers in the Naval establishment. Accordingly, it is the purpose of this article to present some of the information gained on the chemical composition, the physical properties, and the weldability of the steel produced during the emergency period.

The Data.

The requirements of the steel were covered by Bureau of Ships *ad interim* Specification 48S5, dated September 1, 1942. This specification was amended in minor details from time to time. From December, 1942, until May 31, 1944, data were received in the Bureau of Ships for about 600 sample plates. The information from 525 of these samples represents the half-inch plate produced by 6 major plants as follows: Plant A, 101; Plant C, 49; Plant E, 133; Plant F, 36; Plant G, 62; Plant J, 144. The number of samples does not necessarily reflect the relative importance of the different plants on a tonnage basis; it merely reflects the amount of half-inch plate produced. In the discussions on quality control the data received up to October 31, 1944 have been used. This material includes the three types of steel: manganese-titanium, manganese-vanadium, and manganese-titanium-vanadium.

The type of data reported is illustrated in Figure 1, which is the form submitted by the Industrial Test Laboratory, Navy Yard, Philadelphia. In addition to the items of information shown, data were also collected from time to time on other matters, such as the boron and tin content, the grain size, and the stress relieved properties of the steel. Since standard test methods were used, the details of testing procedure are not covered in this article.

A considerable amount of data taken by the Inspectors of Naval Material in the individual plants was also sent to the

Bureau of Ships. This information has been used for keeping a close check on the variations in the product which was submitted for inspection. It proved to be extremely valuable for quality-control work on heavy gauge material. Although the data contained here on half-inch plate are comparable from one producer to another and are invaluable for working out relationships, caution should be exercised in applying the conclusions to material of other thicknesses. The differences in finishing temperatures and cooling rates, and the practice of assigning heats with higher quantities of the chemical elements to the heavier gauges, are a few of the many factors which must be taken into account.

Treatment of the Data.

One of the main functions of a statistician is to reduce the data, which because of their very bulk and complexity are difficult to comprehend. The reduced quantities such as averages, estimates of variation and measures of relationship, contain most, if not all of the relevant information. Since a great bulk of complex data often raises a barrier which prevents proper analysis, it will be of value to describe how this obstacle was overcome by the use of modern computing devices.

The original data were first transferred from the laboratory test reports, to master punch-cards for ease in handling by International Business Machine Methods. Each card contained the data on 28 variables for a single sample. The plant and the report number were identified by means of a code. The data were tabulated on master sheets to provide a ready means of reference for research work. Special cards were than prepared and punched from the master cards for the machine computations described below.

The measures of relationship between the different variables, e.g. the effect of chemical composition on physical properties, requires the calculation of multiple regression statistics. This series of operations is rather complicated when a large number of variables is involved. From preliminary analyses, which were run by hand, it was found that it took a computer about 3 weeks to complete the calculations for about a hundred heats from a single plant. In order to save time and labor on this type of problem steps were taken to use the automatic sequence controlled calculating machine which had just recently been con-

structed at Harvard University. The sequences of mathematical operations for the control tapes were prepared by Miss Marion M. Sandomire, Statistician, in the Sub-section. They have since been used for several similar problems with the same number of variables. One of the operations is the solution of 10 simultaneous equations involving the 10 unknowns, b_1 to b_{10}, in the following equation:

$$Y = a + b_1X_1 + b_2X_2 + \ldots + b_{10}X_{10}$$

where $X_1, X_2, \ldots, X_{10}$ represent the chemical composition, e.g. the percentage of carbon, the percentage of manganese, etc., and Y is the value of a physical measurement, such as the yield point. The solution of this problem, as most engineers will remember from their algebra days, is a tedious one. The Harvard calculating machine does the whole job of calculating the means, accumulating the sums of squares and products, computing correlation coefficients, solving for the reciprocal matrix, calculating the required measures of relationship and the regression coefficients that are needed for the analysis of the data from a single plant. The whole operation takes only about 20 hours and has saved over 800 man-hours on this problem alone.

RESULTS.

It is not the purpose of the article to go into the technical details of mathematical statistics required for this type of analysis, but rather to interpret the results which are presented in the reduced form. Accordingly, the discussion is arranged in three parts:

A. The Descriptive Data. These data form the basis for the development of specifications.

B. The Analysis of Relationships. A knowledge of the effect of the variations in chemical composition and other factors on the physical properties and weldability of the steel is essential for maintaining process control.

C. Product and Process Quality Control. This is essentially the application of the findings to the problem of maintaining uniform quality of the product which is actually furnished under the specification requirements.

A. *Descriptive Data.*

When it was decided to amend the specification for high tensile steel in the early stages of the program, it was found that there were little comparable data on the characteristics of the material produced by different plants. The present contribution will therefore serve as a source of information on the characteristics of the high tensile steel furnished by the industry during the war-time emergency. It is probably one of the most comprehensive collections of data ever gathered on the properties of structural plate for ship construction, and the only one available on the war-time product.

Variability charts showing the variations in tensile strength and yield point in the as received and normalized conditions together with the variations in the most important elements: carbon, manganese, titanium and silicon, are shown in Figures 2 and 3. These data cover the last 25 heats from the 6 major producers received up to May 31, 1944, at the height of the building program.

CHEMICAL COMPOSITION.

Tables 1.1 to 1.10 summarize all the data with respect to the chemical composition of the steel. For acceptance-rejection purposes by the Naval inspector the test samples for chemical determinations are usually taken from the bend specimen, which is taken from the top cut of an ingot. The data reported here came from plates selected at random from the heat. These data, therefore, provide a better picture of the true variation of the product and are undoubtedly more representative. The segregation studies summarized in Part B show the extent of the variations in the heat.

In order to use the information contained in the tables it is necessary to have an understanding of the statistical value called the standard deviation, or *sigma*[1]. It is a measure of the scatter of the observations around the average (arithmetic mean). The minimax range (maximum − minimum) is also such a measure but its reliability is impaired by the fact that, in general, the greater the number of observations, the greater the range will be.

1. Mathematical statisticians make a distinction between the true, but unknown, standard deviation, which is denoted by σ, the Greek letter *sigma*, and an estimate of the true standard deviation, which is derived from data and denoted by s. In quality-control work it has been customary, unfortunately, to overlook this distinction and to call the estimate of the standard deviation, *sigma*. In keeping with quality-control usage the term *sigma* used here means the estimate derived from data.

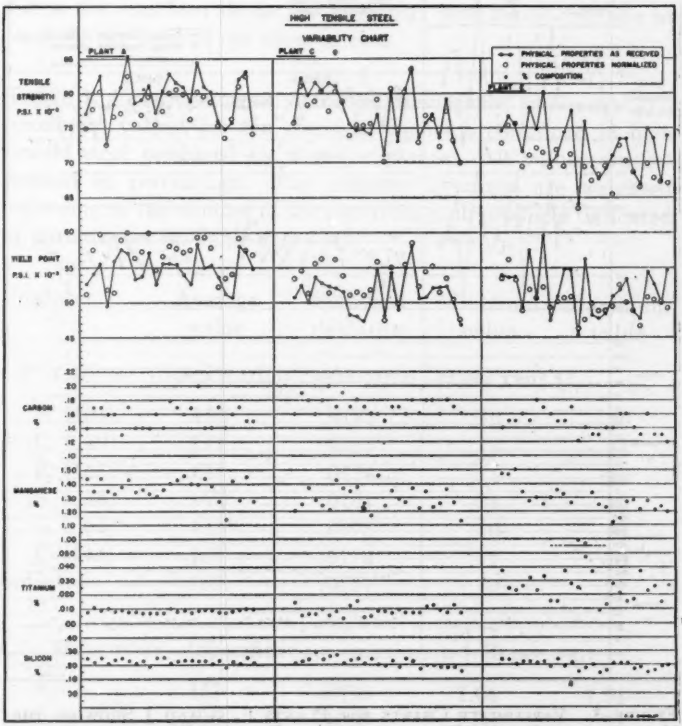


FIGURE 2. VARIABILITY CHARTS FOR PLANTS A, C AND E SHOWING THE VARIATIONS IN CERTAIN ELEMENTS AND THE PHYSICAL PROPERTIES FOR THE LAST 25 SAMPLES RECEIVED TO MAY 31, 1944.

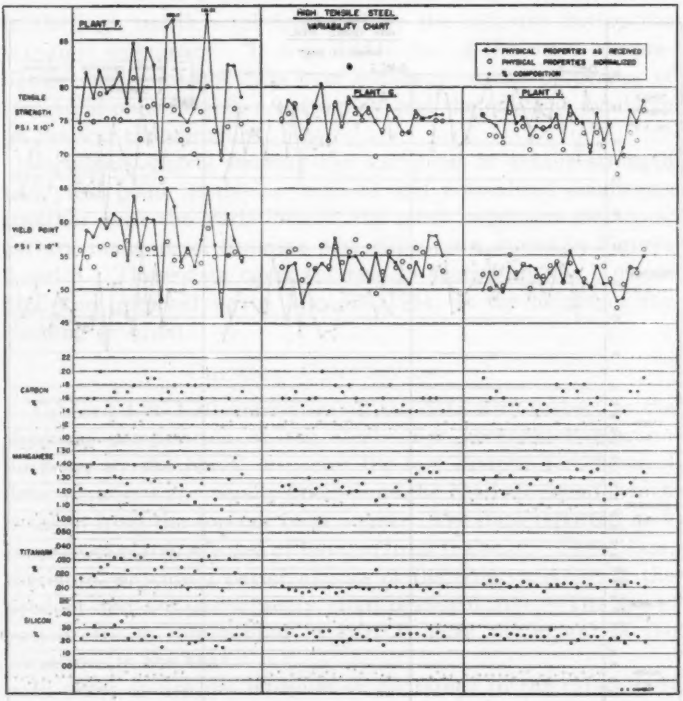


FIGURE 3. VARIABILITY CHARTS FOR PLANTS F, G AND J SHOWING THE VARIATIONS IN CERTAIN ELEMENTS AND THE PHYSICAL PROPERTIES FOR THE LAST 25 SAMPLES RECEIVED TO MAY 31, 1944.

A fairly reliable estimate of the standard deviation can be obtained with samples containing as few as 15 items. The average plus and minus the standard deviation covers a range, in normally distributed[2] data, which includes two-thirds of the observations. A fact of importance in dealing with variable material is that, regardless of the type of distribution—normal or not, the range covered by the average plus and minus three times the standard deviation (3-sigma) will always include at least 90 per cent of the observations.

TABLE 1. The averages, standard deviations, minimum and maximum values, for ten chemical elements contained in high tensile steel produced by 6 major plants. All values are expressed in percentage. The industry averages are weighted according to the number of samples from each producer indicated in parentheses in Table 1.1.

Producer	Average value	Standard deviation	Minimum value	Maximum value
1.1 Carbon	(Specification—maximum .20 per cent.)			
A (101)	.150	.0185	.10	.20
C (49)	.171	.0157	.14	.22
E (133)	.148	.0154	.11	.19
F (36)	.162	.0161	.14	.20
G (62)	.158	.0198	.10	.20
J (144)	.158	.0170	.11	.20
Industry	.155	.0171	.10	.22
1.2 Manganese	(Specification—maximum 1.50 per cent.)			
A	1.332	.0993	1.04	1.51
C	1.300	.1008	1.08	1.52
E	1.277	.1048	0.77	1.50
F	1.244	.1359	0.94	1.48
G	1.224	.0995	1.04	1.41
J	1.330	.0841	1.14	1.59
Industry	1.296	.1000	0.77	1.59

2. A normal distribution is one in which the quantities are so distributed that a normal probability curve adequately describes the data.

Table 1 (Continued)

Producer	Average value	Standard deviation	Minimum value	Maximum value
1.3 Phosphorus	(Specification—maximum .04 per cent.)			
A	.0162	.00498	.006	.033
C	.0165	.00492	.008	.028
E	.0203	.00562	.010	.039
F	.0269	.00708	.008	.040
G	.0188	.00708	.008	.045
J	.0224	.00647	.001	.039
Industry	.0200	.00603	.001	.045
1.4 Sulphur	(Specification—maximum .05 per cent.)			
A	.0273	.00654	.010	.045
C	.0254	.00574	.012	.041
E	.0301	.00680	.011	.048
F	.0311	.00881	.008	.045
G	.0253	.00635	.008	.038
J	.0225	.00572	.006	.039
Industry	.0265	.00648	.006	.048
1.5 Silicon	(Specification—minimum .15 per cent, maximum .35 per cent.)			
A	.231	.0270	.16	.30
C	.211	.0328	.15	.29
E	.232	.0397	.14	.32
F	.231	.0462	.15	.35
G	.260	.0407	.16	.37
J	.251	.0346	.15	.34
Industry	.238	.0362	.14	.37
1.6 Copper	(Specification—maximum .35 per cent.)			
A	.0782	.0432	.01	.21
C	.1245	.0403	.04	.20
E	.0355	.0257	.01	.14
F	.1700	.0418	.07	.25
G	.2081	.0674	.02	.40
J	.1146	.0348	.01	.23
Industry	.1033	.0408	.01	.40

Table 1 (Continued)

Producer	Average value	Standard deviation	Minimum value	Maximum value
1.7 Chromium	(Specification—maximum .15 per cent (March 15, 1944).)			
A	.0865	.0249	.01	.14
C	.1329	.0628	.01	.27
E	.1858	.0769	.01	.34
F	.0558	.0325	.01	.12
G	.0650	.0272	.01	.13
J	.0490	.0220	.00	.12
Industry	.1011	.0478	.00	.34
1.8 Nickel	(Specification—maximum .25 per cent.)			
A	.169	.0482	.03	.30
C	.164	.0403	.01	.24
E	.034	.0205	.00	.13
F	.059	.0246	.01	.11
G	.127	.0388	.02	.23
J	.067	.0245	.00	.23
Industry	.094	.0330	.00	.30
1.9 Molybdenum	(Not specified.)			
A	.0556	.0281	.00	.12
C	.0367	.0272	.00	.14
E	.0319	.0191	.00	.09
F	.0333	.0226	.00	.09
G	.0395	.0190	.01	.10
J	.0311	.0204	.00	.09
Industry	.0377	.0225	.00	.14
1.10 Titanium	(Specification—minimum .005 per cent.)			
A	.00820	.00170	.005	.015
C	.00753	.00338	.002	.019
E	.02811	.00765	.009	.055
F	.02150	.00982	.005	.040
G	.00861	.00308	.005	.023
J	.01455	.00476	.003	.037
Industry	.01588	.00551	.002	.055

The data presented in the tables indicate considerable variation in the practices of the different plants. The steel from Plant C had a very high carbon content which imposed a serious quality-control problem. Plants E and F maintained a high titanium content which acted as an alloy and had a significant effect on the strength of the steel. Plants A and C made additions of nickel to the product, and Plants E and C added chromium. The product from Plant J was remarkable for the very low content of residual elements which are obtained ordinarily from the scrap. The outstanding feature of the analysis of the chemical composition of the high tensile steel produced by the six plants is the diversity of practice which it revealed. Yet, in spite of this diversity, the product met the requirements of the specification within fairly reasonable limits.

Physical Properties.

The data on yield point, tensile strength and elongation are shown in Tables 2.1, 2.2 and 2.3. The total range of heat-to-heat variation for both yield point and tensile strength was about 25,000 pounds per square inch. This is an excessively high spread. It was partly due to the low values for certain heats produced in the early stages of the program. After the recommended quality-control measures took effect the average was raised and a greater control over the variation was achieved. The chief difficulty was the problem of meeting the yield point requirements of the specification. This will be discussed at greater length in Part C.

Weldability.

Although the specification had no test for weldability, other than the controls imposed by the limitations on the chemical elements that are known to cause excessive hardening, a series of Tee-bend tests were run in the hope of developing a satisfactory weldability test for inspection purposes. The details of this test are given in a paper entitled "The Tee-bend Test to Compare the Welding Quality of Steels" by Geo. A. Ellinger, A. G. Bissel, and Morgan L. Williams (Jour. Res. Nat. Bur. Stand., Vol. 28, Jan. 1942).

In order to conduct the test a double-fillet, T-welded assembly is made and cut into 6 specimens. Each specimen is then bent in a jig. The angle at maximum load, the maximum load, and

TABLE 2. The averages, standard deviations, minimum and maximum values for 3 physical properties of the high tensile steel produced by 6 major plants.

Producer	Average value	Standard deviation	Minimum value	Maximum value
2.1 Tensile strength (Specification—Maximum 87,000 p.s.i.)				
	p.s.i.	p.s.i.	p.s.i.	p.s.i.
A	77,800	4,330	65,200	88,400
C	77,600	4,480	69,800	86,300
E	76,500	4,900	64,000	89,400
F	78,700	5,940	67,800	91,000
G	75,800	2,680	68,700	83,700
J	75,900	3,360	68,200	87,400
Industry	76,800	4,230	64,000	91,000
2.2 Yield Point (Specification—Minimum 48,000 p.s.i.)				
	p.s.i.	p.s.i.	p.s.i.	p.s.i.
A	53,000	3,940	41,800	64,700
C	50,600	3,360	44,200	58,000
E	53,900	3,880	44,600	64,000
F	56,400	5,110	44,600	65,200
G	51,600	3,090	44,300	58,100
J	52,200	2,620	45,200	58,200
Industry	52,800	3,290	41,800	65,200
2.3 Elongation (Specification—Minimum 20 per cent in 8 in.)				
	%	%	%	%
A	24.2	2.53	15.4	30.4
C	26.1	2.30	20.8	30.4
E	25.2	2.35	20.0	31.4
F	24.3	2.30	19.0	29.7
G	26.4	1.54	21.7	29.4
J	26.0	1.99	20.0	31.4
Industry	25.4	2.20	15.4	31.4

the type of fracture were recorded. The angle at maximum load was found to have the most significant bearing on the subject. The data in Table 3.1 represent the average angle at maximum load of 4 specimens from each assembly.

TABLE 3.1 The averages, standard deviations, maximum and minimum values for the angle at maximum load in the Tee-bend tests on high tensile steel from 6 major plants.

Producer	Average value degrees	Standard deviation	Minimum value	Maximum value
(No specification limit.)				
A	55.30	10.07	24.0	71.5
C	58.18	9.24	37.5	71.5
E	61.75	6.03	38.0	76.0
F	55.69	8.90	38.8	69.8
G	61.87	6.54	33.0	72.2
J	61.07	6.57	45.0	72.5
Industry	59.67	7.68	24.0	76.0

If a Tee-bend specification limit is ever developed for this steel the data in table 3.1 will be of value. For example, if a lower limit of 50 degrees had been set, then about 10 per cent of the product of the industry as a whole would have been rejected. This result is obtained by assuming that the observations are normally distributed and by making the following calculation:

$$\frac{\text{Industry average—Spec. limit}}{\text{Industry st. dev.}} = \frac{59.67 - 50}{7.68} = 1.26$$

The value 1.26 is looked up in a table of normal deviates, where it is found that about 10 per cent of normally distributed values will have negative deviations exceeding the difference of 9.6 degrees. A limit of 50 degrees would obviously work a greater hardship on Plants A, C and F than on Plants E, G and J. Plant A, for example, using the calculation:

$$\frac{55.3 - 50}{10.7} = .53$$

would have had 25 per cent of its production rejected. Plant E, on the other hand, by using the data:

$$\frac{61.75 - 50}{16.03} = 1.95,$$

would have had less than 3 per cent of its steel rejected.

B. *Analyses of Relationships*

Effect of Chemical Variations on Physical Properties.

The relative independent effects of the ten different chemical elements on the four properties: tensile strength, yield point, elongation and Tee-bend angle, were calculated and the significance of the results is shown in Tables 4.1 to 4.4. The multiple correlation coefficient expresses the intensity of the relationship between the variations in chemical composition and the variations in the different physical properties. This measure can be used as an index of the percentage of variation accounted for by the variations in the chemical composition. The index is obtained by squaring the multiple correlation coefficient and multiplying the result by 100.

In the industry as a whole, the variation in the quantities of the elements selected accounted for about 75 per cent of the total variation in tensile strength. The elements responsible for the greatest part of the variation in tensile strength, as shown in Table 4.1, were carbon and manganese. Variations in the titanium, phosphorus and silicon content had a lesser share in causing variability, and the effects of the remaining elements: chromium, nickel, sulphur, copper, and molybdenum, were negligible. It should be noted that titanium was a very important element in Plants E and F where an average of over .02 per cent occurred. The high tensile steel produced by the industry should be divided into two groups:

1. A titanium-treated manganese type produced by Plants A, C, G, and J.
2. A low-alloy manganese-titanium type produced by Plants E and F.

In the industry as a whole the variations in chemical elements accounted for about 50 per cent of the total variation in yield

TABLE 4. The significance of the effect of variations in the 10 chemical elements, C, Mn, P, S, Si, Cu, Cr, Ni, Mo, Ti, on the tensile strength, yield point, elongation and Tee-bend angle of high tensile steel produced by 6 major plants.

Producer	Multiple correlation coefficient (R)	Very highly significant P<.001	Highly significant P<.01	Significant P<.05	Possibly significant P<.1	Not significant P>.1
4.1 Tensile strength						
A	.8384	C Mn	none	Cr	Ni Ti	5 others*
C	.8900	C Mn Si	P	Cr Ti(−)†	S Ni	2 others
E	.7291	C Ti	Mn Si	P	none	5 others
F	.9355	Mn Ti	none	C	none	7 others
G	.7852	C	Mn	P Si	Cu	5 others
J	.8070	C Mn	none	P	Si	6 others
4.2 Yield Point						
A	.7173	C Mn	none	Ni	none	7 others
C	.8209	Mn	S(−) Si	P Mo	none	5 others
E	.7111	Ti	Mn P	C	none	6 others
F	.7123	none	none	Ti	Mn	8 others
G	.6351	none	Mn	Ti	C	7 others
J	.6862	C Mn	none	P	Si Mo	5 others

*"Others" refers to remainder of elements listed in heading.
†The negative sign indicates an effect in the negative direction.

Table 4 (Continued)

Producer	Multiple correlation coefficient (R)	Very highly significant P<.001	Highly significant P<.01	Significant P<.05	Possibly significant P<.1	Not significant P>.1
4.3 Elongation						
A	.5133	none	C(−)	none	S(−) Mo	7 others
C	.5990	none	none	Si(−)	Mn(−)	8 others
E	.5394	Ti(−)	none	none	none	9 others
F	.8602	none	Mn(−) Ti(−)	none	Si(+)	7 others
G	.6613	NI(−)	none	Ti(−)	none	8 others
J	.4971	none	C(−)	P(−) Si(−)	none	7 others
4.4 Tee-bend angle						
A	.6445	Cu(+)	Si(−)	Ni(−) S(−)	C(−) Cr(−)	4 others
C	.7403	none	Mn(−) Cr(−)	Mo(+)	Cu(−) Ti(−)	5 others
E	.5723	Cr(−)	Si(−)	none	C(−) Ti(−)	6 others
F	.7015	none	none	none	Si(−)	9 others
G	.5268	none	none	C(−)	S(−)	8 others
J	.3852	none	none	C(−)	none	9 others

point. Variations in such factors as finishing temperature probably have more effect on the yield point than they do on tensile strength, thus leaving an unaccounted for proportion of the total variation, which would explain the lower correlation between chemical composition and yield point. As shown in Table 4.2 carbon and manganese were the two elements with the greatest effect on variations in yield point; titanium and phosphorus were next in importance; the effects of variations in the rest: Sulphur, silicon, nickel, molybdenum, copper, and chromium, were negligible. Since several plants were making additions of nickel and chromium, primarily to obtain higher yield points, this finding is a matter of some importance, especially because chromium has a detrimental effect on the weldability.

As shown in Table 4.3 variations in chemical composition had still less effect on elongation than they had on yield point. "Chemistry" accounted for less than 40 per cent of the variation in elongation values. Titanium was the most important element in the group affecting elongation. The reduction of the elongation value by increasing the titanium content is a serious effect to be guarded against in this steel. More extensive studies on this question revealed that the effect of titanium on elongation was probably produced through its effect on yield point. Nevertheless, a high titanium content, i.e. over .05 per cent, does affect the elongation to such an extent that it constitutes a rejection hazard. The effect of the other elements on elongation was negligible, indicating that other factors, not measured, are responsible for the variation observed.

Effect of Chemical and Physical Variations on Weldability.

The variations in chemical composition were responsible for only 35 per cent of the variations in the angle at maximum load in the Tee-bend test. Although it was difficult to establish a very close association between the chemical content and weldability, certain facts do stand out. Chromium, for example, even in the low quantities that the steel contained, had a significant effect on the Tee-bend angle. Individual variations in plant practice, apart from the variations in chemical composition, were probably responsible for most of the unexplained effects. Considering the different chemical elements: In Plant A, silicon was the most important; in Plant C, manganese and chromium·

in Plant E, chromium and silicon; in Plants G and J, carbon. A series of investigations revealed that copper probably had a beneficial effect on the ductility of the weldment, if kept at an optimum level of about .10 per cent.

The variations in physical properties were correlated to an even less extent with the Tee-bend angle than were the variations in chemical content. In the industry as a whole tensile strength was associated with Tee-bend angle to the extent of 20 per cent, whereas yield point and elongation accounted for only 10 per cent of the variations in Tee-bend angle. The results of the analysis indicate rather definitely that important factors, other than the chemical composition and the physical properties of the high tensile steel, are involved in this test for weldability.

Normalizing Treatment.

When the specification for the titanium steel was first set up, a new requirement was written: It was "required to meet the physical properties set forth in the as-rolled and *normalized* conditions". This step was taken to prevent the attainment of the specified yield point by means of cold work.

The yield point of the steel produced by Plants E and F was characterized by a highly significant drop upon normalizing. In fact, one-quarter of the first 25 heats of Plant E were below the specification. In all the other plants, there was either no change or a slight rise. This led to a special analysis of the situation which revealed that the drop on normalizing was definitely associated with the titanium content. As shown in Figures 2 and 3, the extent of the drop tended to increase as the value of titanium rose above .025 per cent. Vanadium was also shown to have the same effect in another series of studies.

Using the data from five of the plants, two prediction equations were calculated which reflect the magnitude of the effect of carbon, manganese and titanium on the strength of the steel in both the as-rolled and normalized conditions:

$$YA = 13{,}800 + 59{,}300C + 20{,}400Mn + 153{,}000Ti$$

$$YN = 16{,}900 + 64{,}500C + 19{,}200Mn + 38{,}900Ti$$

where YA = yield point, as rolled, in p.s.i.

YN = yield point, normalized in p.s.i.

The decrease in the magnitude of the regression coefficient for titanium was even greater for Plant E considered separately, where it decreased from 267,000 to 57,000 upon normalizing.

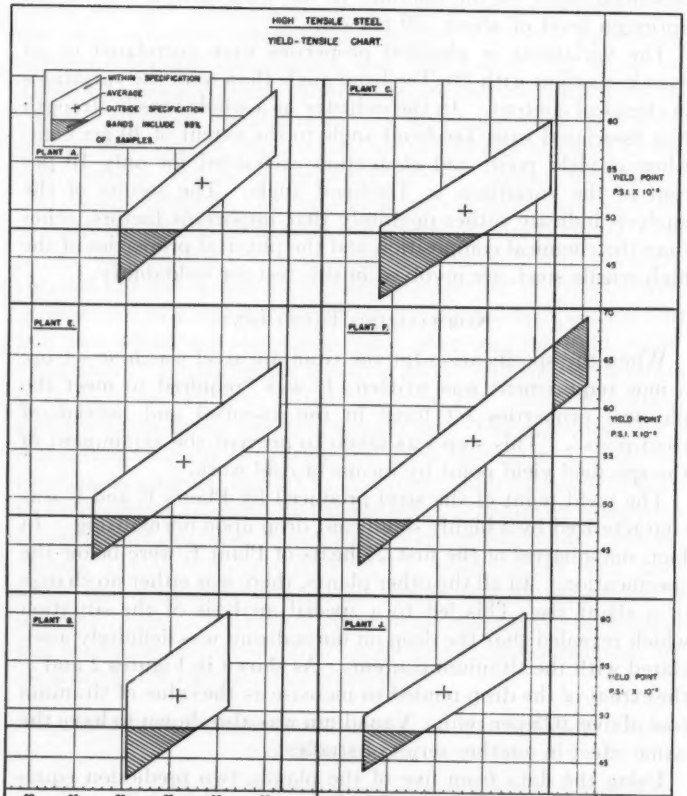


FIGURE 4. YIELD POINT TENSILE STRENGTH OPERATING RANGE CHARTS FOR 6 MAJOR PLANTS.

In Figure 2 there is a noticeable downward trend in the physical properties for Plant E. This appears to be associated with a corresponding trend in carbon. The normalizing requirement, which had been particularly severe on this plant because of its titanium practice, was removed at about the time the first sample in this series was submitted. The effect of changes in specification requirements on plant practice is apparent from these data.

Subsequent to these studies an analysis was made at one plant of the effect of finishing temperatures on the physical properties of the manganese-vanadium-titanium type of high tensile steel which is now being produced. It was found that variations in finishing temperature had no effect on tensile strength, but a drop of 100 degrees F. in the range from 1500 degrees F. to 1400 degrees F., for example, was accompanied by an increase of 5000 p.s.i. in the yield point. To date no way of evaluating the amount of "cold work" in the as-received steel has been developed. Further investigations of the relationship between yield point, tensile strength and finishing temperature should be made. It is obvious that in order to control the cold work factor some sort of process control would have to be specified.

The Yield Point-Tensile Strength Relationship.

One of the important characteristics of high tensile steel is the high yield point in relation to the tensile strength. The former must be kept high for the structural service requirements, and the elements which affect the latter must be kept as low as possible because of the difficulties experienced in welding. A steel, therefore, with a very low yield-tensile ratio is at a decided disadvantage when it comes to meeting the requirements of the specification.

A new type of chart was developed to depict (a) the yield-tensile relationship, (b) the allowable range set by the specification and (c) the actual operating band of each producer. The composite picture has been charted in Figure 4. The average yield point and average tensile strength is indicated by the cross. The operating bands cover a range of twice the standard deviation for tensile strength and should include approximately 95 per cent of the heats produced by each plant. The black areas indicate the relative proportion of the band which was beyond the allowable range. The ratio of white to black areas in the

band is a graphic index of the relative difficulty experienced by the different producers in meeting the specification for yield point and tensile strength.

In constructing these charts, the relationship between yield point and tensile strength was found to be sufficiently linear to use an equation of the form: $Y=a+bX$, where Y is the yield point and X is the tensile strength. The values of the constants, a and b, were calculated by means of the least squares method from the actual data for each producer. The equations calculated for the 6 producers are as follows:

Plant A: $Y=-10.79+.8200\ X$
Plant C: $Y=\ \ 1.83+.6286\ X$
Plant E: $Y=-\ \ 1.27+.7204\ X$
Plant F: $Y=-\ \ 7.27+.8088\ X$
Plant G: $Y=-\ \ 1.82+.7038\ X$
Plant J: $Y=\ \ 2.86+.6503\ X$

Values of Y are expressed in pounds per square inch $\times 10^{-3}$

The regression coefficients describe the slope of the lines. Higher values for the constant, b, indicate a higher yield-tensile ratio. This coefficient can be used to evaluate the influence of factors which have differential effects on yield point and tensile strength. For example, the comparative effect of carbon on yield point and tensile strength for 6 different producers was as follows:

MULTIPLE REGRESSION COEFFICIENTS FOR CARBON.

	Yield point (YP)	Tensile strength (T)	Ratio $\frac{T}{YP}$
Plant A	65.2	81.7	1.25
Plant C	32.2	103.7	3.22
Plant E	42.1	84.4	2.00
Plant F	43.0	63.4	1.47
Plant G	34.0	80.3	2.36
Plant J	48.9	94.9	1.94

It is obvious from the ratios that the effect of carbon on tensile strength is twice that on the yield point. Changes in the carbon content will therefore affect the yield-tensile slope. This means

that if it is desired to raise the yield point, without raising the tensile disproportionately, raising the carbon content is not an efficient practice. Plant C, which maintained a high carbon practice, ran into the greatest difficulty. Plant A, on the other hand, with a very low ratio experienced much less trouble.

The multiple regression coefficients for manganese provide an interesting contrast to those for carbon.

MULTIPLE REGRESSION COEFFICIENTS FOR MANGANESE.

	Yield point (YP)	Tensile strength (T)	Ratio $\frac{T}{YP}$
Plant A	18.4	24.4	1.33
Plant C	17.0	17.8	1.05
Plant E	6.9	8.6	1.25
Plant F	13.3	17.4	1.31
Plant G	14.7	8.9	0.61
Plant J	11.5	16.6	1.44

The values for the effect of manganese on tensile strength are not significantly greater than those for the yield point. Changes in manganese content would, therefore, have an equal effect on the two characteristics and consequently will not change the yield-tensile slope. It will merely move the average along the line of slope.

In order to increase the yield-tensile ratio, without reducing the tensile strength, the procedure indicated by the analysis is to drop the carbon and increase the manganese. As will be pointed out in Part C, increasing the manganese led to welding difficulties and the addition of a less hardening alloy had to be used. The only evidence available indicated that both titanium and vanadium increase the yield point to a greater extent than the tensile strength and are thus desirable alloys for this purpose.

Some factors influence yield point without affecting the tensile strength. The evidence on the effect of finishing temperature indicates that it is such a factor. Its influence is mainly reflected in the value of the constant a which is the Y-intercept in the equation. A decrease in finishing temperature causes the average to shift upward in a vertical direction thus increasing a. A series of studies on the effect of grain size showed that it has

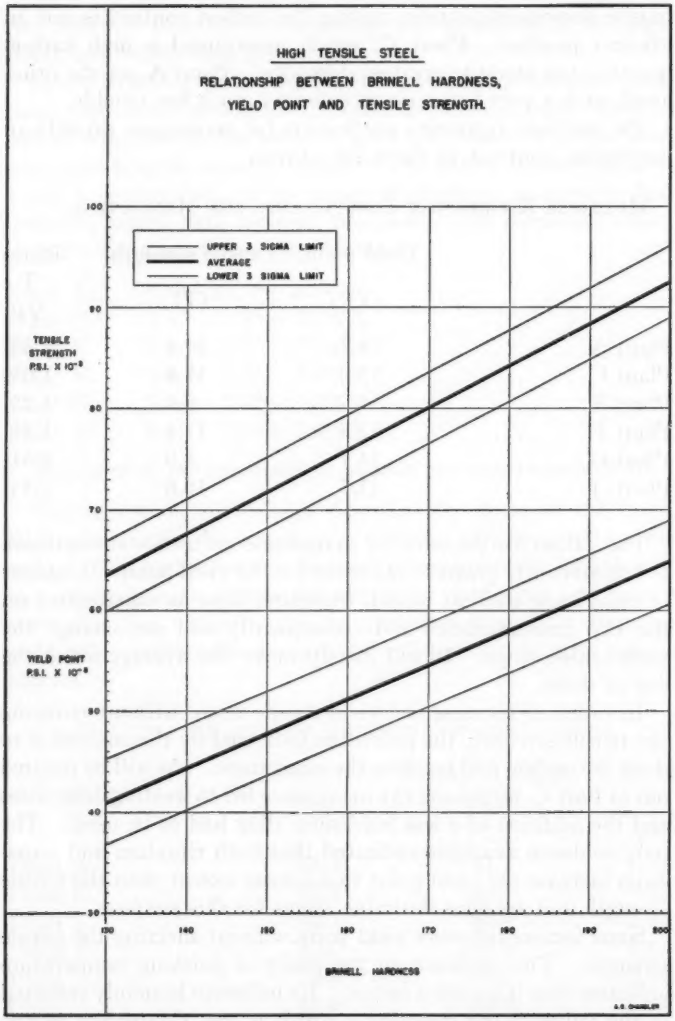


FIGURE 5. THE RELATION BETWEEN BRINELL HARDNESS, YIELD POINT AND TENSILE STRENGTH.

an influence similar to finishing temperature. Actually all of the factors in the production process are so inter-related that any change probably results in complicated changes in both constants. This method of analysis, however, will be of service for developing process control. The actual behavior of the constants should be determined by carefully controlled experiments in which the contributing factors are deliberately varied.

Relation of Brinell Hardness to Physical Properties.

Brinell hardness is ordinarily closely correlated with yield point and tensile strength. If the measurement is properly conducted under controlled conditions, it serves as a relatively simple means of obtaining reliable estimates of these characteristics. In order to screen out hard plates, which required special pre-heat for welding, one of the shipbuilding yards asked for a quick method of determination. The correlations between Brinell hardness and yield point and tensile strength were computed for the different producers. The results showed that there was no significant difference between the product of the different plants in these relationships.

The relationships were expressed:

1. in terms of correlation coefficients:
   (a) for Brinell hardness and yield point, .7891.
   (b) for Brinell hardness and tensile strength, .8638.
2. in terms of the regression equations:
   (a) $YA = .3417X - 3.4021$
   (b) $TA = .4166X + 9.3876$

where, YA = yield point, as-rolled, p.s.i. $\times 10^{-3}$

TA = tensile strength, as-rolled, p.s.i. $\times 10^{-3}$

For convenience in converting Brinell hardness measurements into yield point and tensile strength values the relationships have been plotted in Figure 5. The bands indicate the limits within which the yield and tensile measurements would be expected to fall 99 per cent of the time. This relationship might be made use of to expedite the inspection of individual plates for acceptance-rejection purposes.

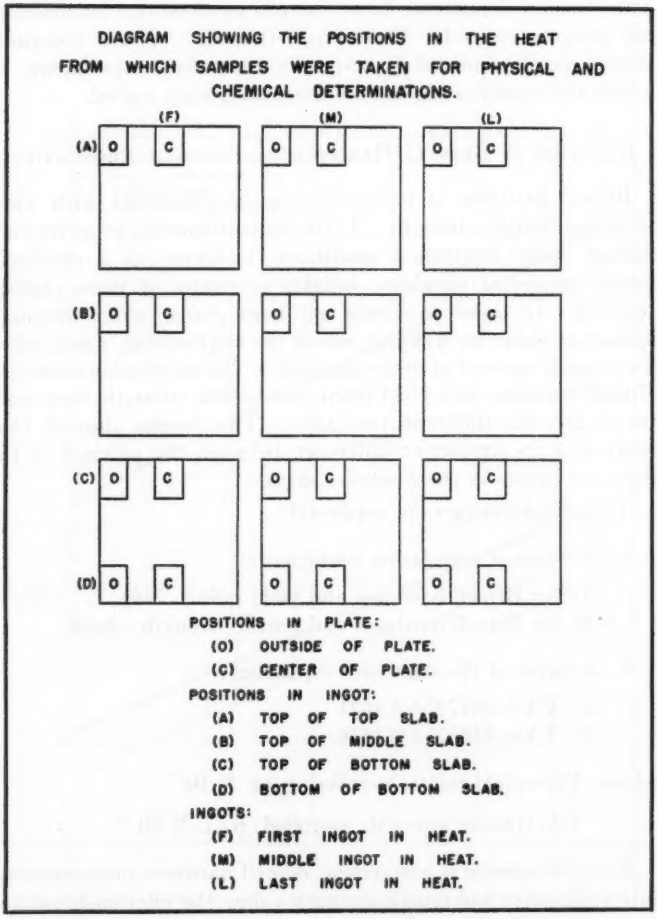


FIGURE 6. SAMPLING LAY-OUT FOR SEGREGATION STUDIES.

Effect of Segregation on the Chemical and Physical Properties.

One of the major problems in setting specifications is to select the best location in the heat from which to take the test samples. Two analyses, one on data from 3 heats submitted by Plant E, and one on similar data from Plant C, were made to determine the extent of segregation of carbon, manganese, phosphorus, sulphur and titanium in the different parts of the heat, as well as the physical properties. The coverage of each heat is shown in Figure 6. Most of the specification limits for the chemical elements are maximum limits; this applies to carbon, manganese, phosphorus, sulphur, silicon, copper, chromium, and nickel. Silicon, titanium and vanadium have minimum limits. The problem is essentially one of determining the positions where the maximum and minimum quantities of the different elements are most likely to occur. The analysis of the variation, using standard analysis of variance techniques, afforded the following conclusions:

1. *Heats.* The variations in chemical composition were highly significant from heat to heat. These results are consistent with other investigations which have shown that the most important source of variation in plate steel is the fluctuation from heat to heat.

2. *Ingots.* The variation from ingot to ingot is not great enough to be of practical importance. There is a slight tendency for the manganese content to be reduced in the last ingots in the heat. In general any ingot selected at random will probably be representative of the heat.

3. *Positions in the ingots.* Very definite segregation occurred with respect to positions in the ingot. Carbon, manganese, phosphorus and sulphur were found to have maximum values in the top of the second cut; titanium on the other hand showed a maximum value at the bottom of the bottom cut. The specifications now require that the specimens for chemical analyses be taken from the top of the top cut. These investigations revealed, however, that higher values will be found lower down in the ingot. The segregation of titanium in a reverse direction to the other elements is a matter of some interest, and studies should be made to determine whether titanium is present in different forms at the bottom and top of the ingot.

4. *Positions in the plates.* No segregation was demonstrable with respect to the outside and center of the plates. Either position seems to be equally representative.

5. *Effect on physical properties.* The variations in chemical composition were accompanied by corresponding variations in physical properties. In general samples should be taken from a position at the top of the second cut to determine maximum values, and from the bottom of the bottom cut to determine the minimum values. The larger the ingot, the greater is the difference to be expected between the top and bottom.

C. *Product and Process Quality Control.*

In normal times product and process quality control can be achieved by setting the desired specification limits and by rejecting material which falls outside these limits. In this case the producer assumes the risk of loss on the rejected material. In some products he can find another outlet for the material which fails to meet Navy requirements. So far, however, practically no other use has been found for high tensile steel produced to the requirements of Bureau of Ships Specification 48S5 (INT). The only important exception is the use for floor plate of thin-gauge material rejected for high carbon or manganese. In war time, when there is a great shortage of labor, material, and production facilities, it becomes important to make the wisest use of resources. The problem, therefore, is one of conservation. The wise procedure is to find out what factors cause rejection and prevent their effects. Ordinarily these steps should be taken by the plants themselves. In a cooperative venture such as this, especially during the full-scale production of steel, impelled by the urgency of war needs, it is more efficient to have a central quality-control unit coordinate the demands of the consumer with the capacities of the producers.

A consumer's quality-control unit should consist of:

1. An engineering group whose specialists are thoroughly familiar with a given product, particularly,
   (a) the production processes,
   (b) the effect of production difficulties on the quality of the product,
   (c) the procurement situation,
   (d) the performance requirements,
   (e) the actual performance under service conditions;

2. An analytical group whose members are trained in modern statistical methods, and who can efficiently

(a) set up representative sampling procedures,
(b) interpret the specification requirements in terms of producer and consumer risks,
(c) analyze data from inspection tests,
(d) design tests and experiments to determine the causes of variation, and analyze the results,
(e) and above all, translate the findings into effective action with the cooperation of the engineering specialists.

After a manufacturer has established his ability to meet the engineering design requirements of the specification, then the chief duty of the quality-control unit is to prepare the evidence necessary for the manufacturer to keep the product within the specified limits. The unit is also charged with another important responsibility. Whenever, as a result of difficulties arising from service conditions, changes are to be made in the specifications, the quality-control unit must see to it that these changes affect the product with a minimum of disturbance.

The procedures used to accomplish these objectives by the control unit consist essentially of the application of scientific procedures to the problems. Modern scientific method is characterized by the extensive use of statistical techniques: (1) to obtain representative data, (2) to analyze them efficiently, and (3) to interpret them on the basis of calculated probabilities. Control limits can be readily calculated from the data. If observations fall outside these limits or, if a significant drift or trend occurs, then it is up to the analyst to call the producer's attention to the fact. In many cases, through an understanding of the relationships between the factors that affect the variability of the product, the quality-control unit can indicate the necessary corrective measures as well.

The quantity of contained silicon is one of the indications of the thoroughness of the deoxidation of the steel. A downward trend was noted in Plant C, as shown in Figure 2. When the operator's attention was drawn to the fact the necessary adjustments were made to correct it.

Although a great many individual analyses of this type were run on the several phases of the quality-control problems, and many corrective measures were taken, space does not permit a

complete exposition of the details. It will suffice to single out one phase of the work for illustrative purposes. In the discussion which follows the quality-control chart of Figure 7 should be referred to as a guide.

The Control of Yield Point.

The requirement which caused the greatest difficulty to the industry, as shown in Figure 4, was the minimum limit on yield point. This requirement is of the utmost importance to the design engineers, since high tensile steel is used to provide increased strength without increasing the weight. Its relatively high yield point is particularly important also for the satisfactory performance of the pressure hulls of submarines. Owing to the difficulty experienced by the industry in meeting the yield point requirement early in the program, the open-hearth aim points were raised on carbon and manganese; small additions of nickel and chromium were also made by certain producers. The relative amount contributed to the yield point by the major elements can be calculated by substituting average values for the chemical elements in the following equation, which was developed in the early stages of the program:

yield point (p.s.i.) = 13,800 + 59,300C + 20,400Mn + 153,000Ti.

According to this, manganese, on the average, contributes about 26,000 pounds per square inch, carbon about 9000 pounds, titanium about 2000 pounds, and all other sources about 14,000 pounds. It is obvious, therefore, that manganese is the most important single contributor to the yield point. Unfortunately, the increase in manganese content resulted in welding difficulties. The situation reached serious proportions in the case of heavy gauge plates. Plant C, the major producer of heavy plate for submarines, experienced the greatest difficulty. The analysis of the test results for Plant C showed that manganese was one of the most significant factors contributing to the reduction of the angle at maximum load in the Tee-bend test. Steel with a high manganese content could be welded, but it required special preheat treatment, which slowed up production.

As a result of the difficulties experienced in the fabrication of the steel it was decided to reduce the specification from a maximum of 1.50 per cent to 1.35 per cent. Manganese is one of the most difficult elements to control in the open-hearth and these difficulties are reflected in the variability of the steel. The data

in table 1.2 indicate that the upper 3-sigma limit is about 1.60 per cent when the average is about 1.30 per cent. In the case of Plants A, C and J, which maintained a high average manganese content, the rejection hazard for this factor alone was over 2 per cent. The reduction of the maximum to 1.35 per cent meant that the average would have to be dropped to at least 1.15 per cent, if the same rejection hazard were to be maintained. Lowering the average manganese content would result in a lower yield point, provided no other changes were made to compensate for it. Notice what this would mean. The yield point for the industry averaged about 52,600 pounds per square inch with a sigma of 3290 pounds per square inch. With the specification limit at a minimum of 48,000 pounds per square inch, the rejection hazard was about 8 per cent. If the average manganese content were reduced by .20 per cent the yield point would be reduced by: $.20 \times 20{,}400 = 4080$ pounds per square inch. The rejection hazard would then be about 45 per cent, obviously a prohibitive value.

The following possibilities were considered to offset the reduction of the maximum limit for manganese:

1. Exercise greater open-hearth control over the variations in manganese content. Closer control would reduce the operating limits so that the average might be maintained at a higher level.

2. Take a greater risk on the rejection of heats with manganese over the specification limit. The producers were not willing to make a significant concession in this regard.

3. Change the specification by lowering the yield point requirements. This was impossible because of the structural design requirements.

4. Offset the reduction in manganese by adding some alloying element with less hardening characteristics. Plant E, for example, with about the same operating range on manganese content as the others, and a slightly lower average than the industry as a whole, produced steel with an average yield point of 53,900 pounds per square inch. Their rejection hazard was about 4 per cent. This advantage was obtained by adding titanium in higher quantities. The other producers claimed that titanium was too variable to use, and hence, they did not capitalize on its possibilities as an alloy. The majority of the producers were in favor of using vanadium, and, when it became available, its use was permitted by a change in the specification.

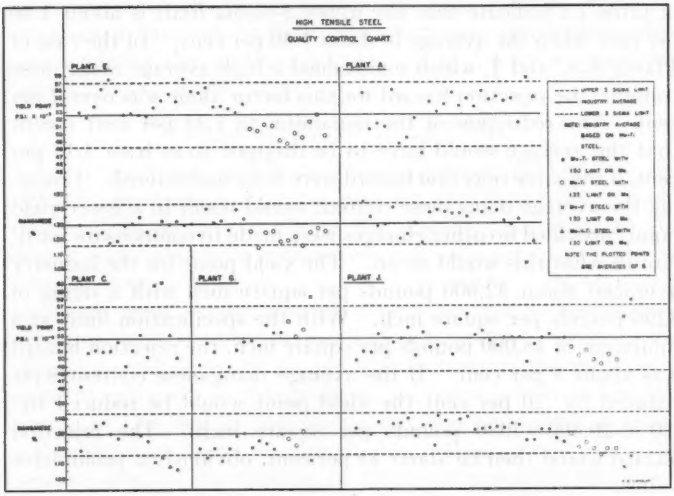


FIGURE 7. CONTROL CHARTS FOR YIELD POINT AND MANGANESE.

The greatly increased yield point achieved by adding vanadium, in spite of the reduction in manganese content, is illustrated in the control charts of Figure 7.

SUMMARY.

The foregoing account of the application of statistical methods to the development and quality-control of high tensile steel is a summarization of some of the more important research reports which were prepared on the subject. It gives a brief history of the development of the steel and describes the organization of the unit which tackled the problems of quality-control. A record is given of the chemical composition, physical properties and weldability of the manganese-titanium types of high tensile steel produced during the war emergency period after vanadium became critically short. The use of the latest developments in computing devices to solve the multiple regression problems, involving the effect of 10 chemical elements on the physical properties and weldability, is also described. The relation between yield point and tensile strength, the effect of the normalizing treatment on the physical properties, and the relation between Brinell hardness and the physical properties are dis-

cussed. A typical quality-control problem, dealing with the yield point requirement in relation to the changes in the specification limit for manganese is treated in some detail.

ACKNOWLEDGMENTS.

Many individuals cooperated to bring the project to a successful conclusion. Special acknowledgment should be made for the leadership and guidance given by Capt. T. A. Solberg, U.S.N., Head of the Research and Standards Branch, and to his assistant, Capt. W. C. Latrobe, U.S.N. Many of the detailed analyses drawn upon here were ably conducted by Lieutenant Daniel R. Embody, U.S.N.R. and Ensign Margaret G. DuVal, U.S.N.R. Many of the pit-falls of mathematical statistics were avoided by the competent help given by Miss Marion M. Sandomire.

The intimate knowledge of the metallurgical and production aspects of the problems, contributed by Lieutenant Commander E. J. Touceda and Lieutenant (jg) F. R. Steckel, was responsible in a large measure for the success of the quality-control program.

"METALS IN WAR AND PEACE."

By Captain T. A. Solberg, U.S.N.*

Introduction.

Although the war itself is a long way from being won, I think it is reasonably correct to say that we are justified in celebrating an industrial victory. The challenge to produce great quantities of everything necessary for war purposes is being met to an extent never envisaged by the most optimistic. This factor is enabling us to place our shots well against our enemies. It is most important to my mind that we profit in the future by this war experience, and even more important that we continuously develop and progress after the peace at a rate at least equalling that which we found so necessary during the war. How much better prepared we would have been at the beginning of this war if only we had worked at this speed the years preceding the war!

Much of the success of the Bureau of Ships in this war can be ascribed to cooperation—cooperation within the Navy—between the Navy and industry—between the Navy and Army, the allies, and the many war agencies and special committees. We have tried to see the other fellow's point of view wherever practicable, and have realized that his problems must be solved as well as our own. We have attempted by use of the large laboratory facilities of the Navy to determine, for example, how best to modify hundreds of specifications in order to speed up production; how to establish quickly the merits of a substitute material; how to supplement the research programs of manufacturers with our own in order to obtain information as quickly as possible. We are keenly aware of the many advantages which have been gained by this wide cooperative effort. On our side, we hope that some of the work of our laboratories has been helpful to science and industry as their work has been to us. I cannot urge too strongly that every effort be made on both sides to continue *after the war* that splendid cooperation in research, development and manufacturing processes.

*From a talk delivered before The American Society For Metals, October 16, 1944.

To digress for a moment, I should like to remind you that even as far back as 1566 the importance of metals in war was realized. A translation by Mr. Hoover from the latin "*De re Metallica*" reads as follows: "Iron is used not only in hand to hand fighting, but also to form the winged missiles of war, sometimes for hurling engines, sometimes for lances, sometimes even for arrows. I look upon it as the most deadly fruit of human ingenuity. For to bring death to men more quickly we have given wings to iron and taught it to fly. The spear, the arrow from the bow, or the bolt from the catapult, and other engines can be driven into the body of only one man, while the iron cannon ball fired through the air, can go through the bodies of many men, and there is no marble or stone object so hard that it cannot be shattered by the force and shock. Therefore, it levels the highest towers to the ground, shatters and destroys the strongest walls." That very old prophesy certainly has come true.

As I stand facing a battery of recognized experts covering all branches of metallurgy, I hope you will bear in mind that a naval officer, even if assigned to engineering duty only, seldom is, and seldom should be, an expert in only one line of the field of engineering. But metals predominate in so many phases of naval engineering that the subject of metallurgy is of continuing interest to all naval engineers. In fact, it is safe to say that our interest in metals is more than merely static; it is progressive and forward-looking. The navy is promoting research and development in the field of metals continually.

When I returned to the new Bureau of Ships in March of this year, my attention was focused, for reasons too long to explain, on the subject of metals. My first survey of the situation convinced me that we were far from having reached the ultimate in any branch of this important field.

Although I had considered our steel specifications in the period of 1935 to 1939 as excellent, and in 1944 as still better, I now felt because of several controversial specifications which came to my attention, that much work remained to be done in the field of steel specifications. It was true that we had built many ships which were giving a good account of themselves in battle. It was true also that much investigational work was in progress. One fortunate tool or approach to the problem was a study of all the data by statistical analysis for the purpose of

establishing more significant information to be used in this development. Some of this work was under way and already indicated that variables previously not considered must be the subject of extensive study.

It has become increasingly evident that although steel in general meets the physical tests required by specification, it performs erratically when subjected to conditions other than those represented by the conditions of normal uni-axial loading at room temperature as experienced when a test bar is pulled in the conventional testing machine.

Our ships are called upon to perform under the most severe conditions imaginable. In many critical situations they are subjected not only to static loads but also to high dynamic loads which may be uni-axial, or multi-axial. The effect of low temperatures also has come in for consideration. Consequently, in order to obtain more information on these subjects it has become necessary to sponsor new investigations. Much of this is being done cooperatively with the Maritime Commission and the Coast Guard, not only in our own laboratories, but also through the channels of the National Defense Research Committee. These investigations seek answers to such fundamental questions as the effect of high speed loading, of multi-axial loading, and crack sensitivity. The question of evaluating the factors affecting the weldability of various steels and the history of residual stresses from welding comes up repeatedly. That this work is necessary and vital is apparent when it is realized that very large sums are being spent to correct existing defects in many merchant ships.

It would be wrong to give the impression that most of our work is focused on ferrous metals. The non-ferrous group necessarily has been given a great deal of attention. Efforts to speed production have resulted in the standardization of specifications for certain cast copper base alloys in cooperation with the American Society for Testing Material, Society of Automotive Engineers, Federal Specifications Executive Committee, and War Production Board. As a result of this standardization, the same alloy may meet the technical requirements of the specifications of the above agencies, so that when a foundry casts a material such as "valve bronze", it is not required to produce special heats with slight variations in alloying elements for the Navy, the Army and industry. The application of non-ferrous

alloys in the Naval service is dependent to a large extent on resistance to the corrosive action of sea water or sea atmosphere, and in this way differs from usual commercial application. For test purposes, the Bureau of Ships maintains extensive corrosion testing equipment at the U. S. Naval Engineering Experiment Station on the Severn River at Annapolis, Maryland. It is at this station that much of the Bureau's metallurgical work is accomplished. Here ferrous and non-ferrous metals and alloys are tested under conditions simulating those found in actual service. It should be remembered that shock incident to gunfire and underwater explosion, vibratory stresses peculiar to ship operation, corrosive conditions and other factors pertaining to the operation of naval vessels dictate what materials may be employed. The requirements placed in navy specifications therefore may necessarily differ in some respects from those which would ordinarily lead to satisfactory behavior in non military service on land. From time to time producers of material for the Navy have lost sight of these peculiar requirements, a fact which has led to some necessity for clarification. May I suggest that you bear with us in this matter. Many developments in specifications for non-ferrous alloys have been based on our own laboratory tests. The addition of .25-.60 per cent iron to 70-30 copper-nickel alloy to improve corrosion resistance, and the addition of .50 per cent tin to manganese bronze to retard dezincification, are specific examples. But a great deal of credit is due to the inventive genius of industry for the development of non-ferrous alloys for our uses. In such cases, the Naval Laboratory serves as an evaluation agency to determine whether or not a commercial product meets the Navy needs or, if not, what changes must be made to fit the product to naval requirements. On the basis of such tests, technical personnel from the Navy have worked with industry to lend their experience to the solution of the development in the spirit of complete cooperation. Examples of such development are the use of chromium plating for internal combustion cylinder liners, the use of 20-80 tin-lead solder for certain applications; the investigation of low tin babbits; the application of metal spray, chromium plating and welding to the repair of certain worn parts; and the use of impregnating compounds and welding for the salvage of bronze castings under certain limited conditions.

During the war it has been increasingly evident that newer

and more powerful tools must be developed for the purpose of non-destructive inspection of castings and forgings. Much work has been accomplished along these lines, particularly in the field of X-ray radiography, utilized by the Navy as early as 1932. Prior to that time most inspection was done by destructive means. Today, radiographic inspection is being done in minutes instead of hours by means of million-volt machines. In order to extend the value of high voltage radiography, the Navy is now cooperating with the National Defense Research Committee in developing and building a 20 million volt betatron machine. With this unit, the time necessary to radiograph a heavy wall will be reduced, and it will be possible, obviously, to radiograph heavier sections than heretofore could be accomplished. The rays emitted by the betatron are of such a nature as to obtain better definition and sensitivity. As many of the problems of the Navy are associated with the construction of high pressure equipment, it is expected that this new instrument will be of great value.

As a result of radiographic inspection it has been possible to examine large castings which have been used in place of forgings, and in such a way the Navy has been able to meet many of its schedules which otherwise would have been impaired by the bottle-neck situation existing in the forging industry. Several years ago, for example, heavy crank shafts were only used in the forged condition and today many of them are cast.

Much radiographic work is being done on Navy material by outside private laboratories who are qualified by the Bureau of Ships after they have demonstrated their ability to perform this work in accordance with bureau requirements. Some twenty-eight laboratories have been qualified, and as a result, a considerable advance has been made in the standardization of all radiographic work. Of almost equal importance in the chemical testing has been the increasing use of the spectrograph. Much work still remains to be done to get better standardization and this project is well under way in our laboratories.

The Navy also is concerned greatly with the relatively new field of high temperature alloys and much research has been directed along such lines. The successful application of alloys which will perform satisfactorily at high temperatures will provide for superior superchargers, rockets, and gas turbines. It is obvious that all research directed along such lines is of great importance. New alloys for high strength at elevated

temperatures for aircraft and ship application have been developed and investigations have been conducted for the last three years by cooperating laboratories of the Navy, Army, National Defense Research Committee and industry, with the result that promising materials are now available. Much research must be completed in this field before the ultimate is reached. A major part in this program has been played by industry, which has pooled information and made it available. *It is of the utmost importance that this cooperation and general pooling of information be maintained.* Current research is at the present time directed along such lines as discovering new compositions and to improve the workability and castability of such alloys as are found to have:

1. Resistance to corrosion fatigue at high temperature.
2. Resistance to creep and alternating stress at high temperature.
3. Resistance to high temperature notch sensitivity.
4. Uniformity of characteristics over ranges of temperature from room to operating conditions.

The organization to which I was assigned was fortunate in having a group devoted to statistical quality control. Their members were adaptable, forward-looking, and had a general knowledge of many scientific subjects; moreover, they were able to assimilate the essentials of any subject quickly. Consequently they were brought into the picture on specific metal problems involving our needs and our specifications. High tensile structural steel specifications were a case in point. These steels were purchased on the basis of chemicals and the usual physical requirements. There was some question, however, as to what represented the optimum composition and what constituted the best treatment from the standpoint of weldability, resistance to the underwater explosion type of impact loading, and ballistic performance. These factors are now being correlated by statistical methods. This same group is serving another valuable function. They are analysing many of our test procedures and methods. From this work, perhaps what might be called a new art is developing, which for the present is being labelled "The Design of Tests and Experiments."

In connection with this work there have been instituted comprehensive studies and tests of some of our alloy steels.

This could not be done without the action and whole hearted cooperation of all the steel companies. They have furnished us many heats of varying compositions. Already in the case of one steel we have progressed to the point where it will be possible to obtain the necessary requirements with only about one-fourth of the critical alloying constituent formerly used.

No doubt many of you have noted the increasing importance which daily is being placed on the use of statistical analytical methods. This certainly has ample justification, for the human mind is incapable of dealing at one time with large numbers of different factors having inter-related effects. A complicated mass of data must be condensed so that it can be expressed in relatively simple terms; yet, this must be done without loss of significant information. Modern multiple regression theory provides a powerful tool for attack on such problems. The results obtained in this method of analysis are regarded as being particularly significant because they are related to and based upon actual commercial conditions of operation and not to idealized situations capable of realization only in laboratories.

The war emergency has created the necessity for conserving critical alloys and has forced research and development to determine the least amount of alloying elements necessary to produce material suitable for the use intended. In following the results of investigations it has become apparent that for many years we as a nation have been wasting alloying elements by requiring greater percentages than necessary for the desired performance in many applications. Let us bear in mind that there is a practical limit to the amount of many of these alloying constituents existing in the world today and it is up to us to determine the least amount of each that is necessary for our present use, in order that these alloys may be available for posterity.

There is much basic and fundamental information available in all fields of metallurgy. We are indebted for much of this to many of the metallurgists who early in this century pointed the way to the advantages to be gained by various alloying constituents. These scientists, however, were handicapped by a lack of friends and facilities, as well as by often having to combat resistance or apathy to rapid and all out progress.

It is true, too, that rapid strides have been made in recent years both by science and industry. But have the advances been

great enough? Surely our present metals and their respective applications can be improved. In the light of some of the early results we have had in our own present investigations, I feel that one message I can give on this occasion is to suggest that we realize that we are far from having reached the ultimate in the field of metals. We must remember that there is a future to be faced. We cannot afford to stop in our tracks when this war is over. We must be forward-looking and forward-thinking. We must continue the development of metals for the sake of everlasting preparedness against any future enemy. But we must also continue the development of metals to make the peace-time world a better place in which to live.

To gain new advances will require the fullest cooperation of science and industry. Industry must be prepared to support the scientist with large expenditure of money and labor, and must be willing to "take chances" on new and experimental processes and manufacturing methods. Both science and industry must maintain an open mind.

Conclusion.

Under the stimulus of this great war, our scientific universe has been tremendously expanded. Our fronts in the fields of medical science, metallurgy and electronics have pushed forward no less rapidly than our fronts in the field of battle. It has been estimated that scientific progress of the last two years surpasses that achieved in a decade of normal peace.

We are fortunate in having great natural wealth in this country; we have an abundance of such resources as oil, coal, minerals, and timber. Yet the great strength of this nation of ours lies not in these things, but in the minds and hearts of our people. Inventive genius, productive skill, and moral courage are required to mould these physical things to great purposes.

With all of its manifestations of evil, war has wrought this one thing of good. It has unified our nation; we have worked cooperatively as a team, knit closely together in a common cause. Selfish individual and sectional interests have been subordinated to the general good, to the end that the nation, the whole nation, might advance down the road to victory.

We have demonstrated tremendous power as a nation to wage war, and this is no less a tribute to the workers on the scientific front than to our gallant people who are waging battles on distant

seas and foreign shores. Through force of circumstances, we have had to concentrate on building great forces of destruction, but we fervently hope that the time is not far distant when we can turn our attention to other things. First, we must win the war; then we must work together to make this a better world in which to live.

We are faced with a grave challenge: *Can we pour these same energies which are bringing us victory in war down constructive channels, with undiminished intensity, to build, in the future, an even stronger, greater nation?*

POST-WAR RESEARCH AND THE NAVY.

By Captain J. E. Hamilton, U.S.N.

There appears to be at least one element in the United States which is fully appreciative of the futility of maintaining armed forces in peacetime without, at the same time, maintaining an effective program of research. One hears this statement in private conversation and in public addresses.

To both the speakers and the enthusiastic listeners, the meaning of research and what it means to the Navy may be somewhat cloudy. To some of them, certainly, it means the work which is done in laboratories by physical scientists, chemists and others in trying to wrest more knowledge from nature. Surely, that is the beginning.

There is no field of applied science which does not have some pertinence to the responsibilities of the Bureaus of the Navy Department. In the perfect naval vessel of whatever size there is some possible application for any device which will add to the offensive power or defensive strength of that vessel.

With that introduction, what research should the Navy take an active interest in and in what way should it be directed and applied? Research of the laboratory variety is conducted, usually, either by individuals who have the means and the wish to learn for knowledge's sake or to seek for new principles which can lead to the development of new devices of commercial value.

Principles having been established and tried by basic research, they are still rarely ready for the pay-off. These principles are usually in the nature of cause and effect relationships. They establish the tools of fact which the inventor uses to bring forth devices or processes which have a practical application in obtaining desired results when applied or operated. An invention can be complete on paper. It can be satisfactorily demonstrated to be sound in principle and correct as to application without working a particle of solid material. Yet, at this stage, its only value is in the satisfaction it gives to the inventor.

The invention may be of such nature that it can be manufac-

tured. That is: it merely needs the construction of pieces to a certain design and their assembly to produce the thing invented. Or it may be in the nature of a chemical reaction or of reaction to heat treatment or something of that kind so that further invention may, and further development will, be necessary to devise a practical process for its advantageous use.

The Navy, or anyone else who is to benefit from the fruits of fundamental research and of invention, must see that everything necessary to translate the original thought into a working application is done. If the invention is a device, one of them must be manufactured and tested to prove in a practical way beyond the Euclidean method that it will work. The details must be tested to be sure that the correct materials are used in each place. They must also be tested to assure that duplicate manufacture, whether of a few or of a large number, is practicable.

When assurance is reached that the device is a practical one, the next step is to prove it by actually setting up the facilities for its production. The nature of these facilities must be influenced by the rate of production required. The invention can be considered as available for use when productive facilities, using practical processes, are ready and proven. It is, however, only available. It cannot be used until it is produced and installed in the place where its use can pay dividends.

In commercial enterprise, research will run the whole gamut from the fundamental or discovery of new principles to advertising to create the widest and most lucrative markets. The final test is in the financial balance sheets. In the Navy the field is just as wide but there can be no satisfactory final test. The usually accepted final test of battle is not absolutely satisfactory because the nature of modern war is such that the fully satisfactory test of a Navy's effectiveness is the prevention of war and hence the absence of battle. However, the test of battle can be made as an hypothesis and proved to the satisfaction of experts. Will it be effective in battle? There are many ways of proving the probability of an affirmative answer.

The United States will enter the post-war period with the largest Navy the world has ever known. Most of it will represent designs of 1940 and later, and in its ships will be incorporated almost all of the applicable fruits of research which have been

brought to the stage of practical availability by the end of the war. It is from that point that we must begin.

Probably the first thing which will be done with the fleet, and in that I include every vessel, boat or ship, on the Navy list, will be a division into three groups. These will be the active vessels to be kept in operation, the inactive ones to be kept available but currently out of service, and those to be scrapped or otherwise disposed of.

The second thing will probably be a further reduction in the number of vessels to be retained and additional scrapping as a result of international agreement. Just what form this will take is impossible to foretell.

The third thing, although conceivably these last two may be reversed in sequence, will be the establishment of the Navy's operating budget at a minimum figure. No longer will it be possible to receive from Congress appropriations large enough to do everything which the Navy would like to do.

The three phases mentioned will be historically repetitive and absolutely sound. The economic life of the country will demand that the Navy's share of the expenditures of the Federal Government be reduced to the least possible amount. That isn't something to charge to an administration or to Congress. It is essential.

Also, the future of the world will require that armaments be stabilized in some manner so that aggression is discouraged and, that failing, impossible of upsetting the world because preventive force will be available for use by the non-aggressive communities.

The Navy, by which I mean those individuals who talk and act as representatives of the Navy Department, will have to favor the reduction in the size of the fleet and then the maintenance of that fleet with a minimum expenditure because they are people of sound judgment. At the same time, their responsibility will make it incumbent upon them to insist on the retention of the fleet at a proper size against any wild-eyed dreamers and on the maintenance of that fleet in proper condition against any dreamy budget parer.

It seems safe to guess that the first step of putting the fleet on a peacetime basis will be done using sound military-technical judgment. Ships which through design or damage are of minimum military value and the most expensive to operate, beyond

the requirements to be retained, will be scrapped and can be forgotten.

Presumably, the division of retained ships can be into two or more groups. That is: "In Commission" and "Out of Commission" only, or those two with an intermediate group, or groups "In reserve" in varying degrees of readiness for service. In addition, it is hoped that there will be maintained a building program sufficient to

(a) Develop new designs
(b) Maintain a nucleus of ship design know-how
(c) Maintain a nucleus of ship construction know-how
(d) Prevent an abrupt obsolescence of the fleet because it was all constructed in a span of only about five years.

Can the Navy's research program be planned around the three groups: Active vessels, inactive vessels, and vessels under construction? It can. Can it be so planned as to be subservient to an *imposed* budget? It cannot.

The program must be so well and logically drawn up that it dictates the budget and that the budget makers will support it. It still does not need to be extravagant.

In thinking of research, we must, at this point, set aside the picture of a laboratory. The work done with scientific equipment in a laboratory is only a part of the whole. Research, to lead to improvement of the fleet, must start from both ends. From the laboratory of the scientist, the Navy must glean every discovery of possible advantage. From the laboratory of the operating fleet, the Navy must obtain reports covering every detail where improvement is possible and every suggestion for effecting that improvement.

To cover all of the possible angles of the Navy's research program, it is necessary to approach it organizationally. Organization brings out the thought of responsibility. Since invention cannot always be forced, the initiation of research cannot be completely codified. The first thing to be set up is that every individual in the Navy and every other citizen to the extent that his interest can be brought in, should bear the thought of continuing improvement. It is his responsibility to initiate action which will permit the Navy to check as to applicability every possible fruit of outside research or invention. It is his responsibility, if he is

on the spot, to thoroughly and carefully analyze every failure of operation or performance or every less-than-best performance to permit the next tier of responsibility to initiate research to overcome the defect or to improve the operation.

On the other side is responsibility for a continuous study of the results of research and invention by all commercial and educational agencies, the general public and others. This authority must put itself in a position to obtain broad covering information and to analyze this information with the Navy's vessels in mind.

We now have the bases on which to erect the Navy's research program. On the one hand is thorough knowledge of the fruits of research outside the Navy. On the other hand is detailed and continuous knowledge of wherein the Navy's mechanical equipment can be or might be improved. Where the two do not dovetail, the Navy's basic research program must cover the missing area. It is only here that the Navy must support research laboratories and maintain personnel whose minds are free to think along scientific and engineering lines.

From the Navy's laboratories will come discoveries and ideas which can lead to improvement of naval installations. From outside laboratories will come discoveries which are shelved as not applicable to commercial development. These latter must be searched and tested for possible Naval applicability.

The next stage is that of development. This is the field of invention and design. Means must be found for translating the ideas and discoveries of the laboratories into devices which can be built and used. This requires the development and construction of a model and its test.

Concurrently with the development of strictly naval research is the test of applicability of applied commercial research. Those things which are put on the market because they can be (or someone thinks they can be) sold at a profit in commercial quantities will include some which will have no use to the Navy; others which can have, but require further development to fit them for the rigors of naval service; and still others which may be modified to fill a naval purpose quite different from the intended commercial purpose.

These two sources of material, naval research and commercial development, lead to the requirement for laboratories of applica-

tion. From these laboratories should issue working, practicable, hand-made models which have proven under laboratory conditions that they can perform a function in naval installations.

In some cases the models will be ready for production with every assurance that they will contribute "as-is" to improvement in naval performance of some kind. In others, still more work must yet be done. For these, the next step is a service test in the type of vessel, sea or air, in which the device is expected to perform. During this initial shipboard test with special care and observation, the device will be proven, or will be improved to remove bugs which develop in operation. This will lead to a production model or to abandonment.

If the development proves worthy of continuance, the production model must be built in small quantities and issued to the fleet or installed in a few ships to provide a real service test. During this test period, the research people should keep away from the thing. What is wanted is an objective trial under service conditions with run-of-the-mine operators. For each test installation, research personnel should set up in a way easy to comply with, instructions for operating personnel to follow both in using the device and in reporting its performance. From these service reports come the information on which final design is based as well as the decision as to how and to what extent the device should be applied.

The last stage is the one in which the Navy was least effective before the war. This was due largely to operating inside an horizon limited by small budgets but was also abetted by a spirit among some naval personnel of opposing alterations to ships. True, many alterations are wasteful and can never pay dividends. This is usually due to a neglect of some of the preliminary steps outlined above.

It has been stated that presumably there will be three groups of ships: (a) the building programs which will include ships about to be started through those in all stages of construction right up to readiness to deliver; (b) those in commission and comprising the operating fleet or fleets; and (c) those laid up out of commission but presumably ready for service if an emergency arises. Each of the three must be considered in reaching a decision as to the application to be made of the new device, or idea.

The elements which have to be thrown together in order to arrive at a decision in this matter are:

(a) Will the thing, as far as can be ascertained or judged, give a vessel a means of offense against which other naval vessels have no adequate defense?

(b) Will the thing give the vessel a means of defense against a known weapon where it now has no, or inadquate, means of defense?

(c) Will the thing improve the habitability or internal supply system of the vessel to the extent that it can remain available in an active area longer or can remain in contact with an enemy longer?

(d) Will the thing improve the morale or physical condition of the personnel appreciably?

(e) Will the thing require the removal of some facility which the vessels now have and must retain?

(f) To what types and classes of vessels does the thing apply?

(g) How long will it take to assemble material including the new device and to make the installation on all vessels affected, or to make the rearrangement or change to incorporate the new idea?

(h) How long will making the improvement immobilize the vessel affected?

Each of the above elements requires judgment, to a certain extent arbitrary. Each of them, in different cases, will vary in degree from minor to vitally major. However, with each one answered and the degree of importance known, a decision can be reached. Cost in dollars has not been mentioned because at this point it should not be considered. Decision as to whether or not a thing *should* be done must not be influenced by monetary considerations. It will be found in practice that no matter how definitely the thing should be judged essential, its actual realization will depend on money. The responsibility for deciding that an improvement should be made rests on the Navy and must be based on sound technico-military judgment. Responsibility for deciding whether it shall be done rests on Congress, in most cases, because the Constitution gives Congress control of the purse strings.

In deciding that the thing should be done, every type and class of vessels must be considered. In some cases, each individual vessel must be separately considered. Judgment here will determine whether a vessel will continue to be a first line unit available for unlimited duty of her type, or must be relegated to the second line. First and second line do not mean "in commission" and "out of commission" respectively. Operating plans will almost always require that some second line vessels be kept in commission, and certainly, at the end of this war, we will have many first line vessels which will have to be decommissioned for retention for first line service in the event of loss of vessels kept in commission, or for use in a future emergency.

As examples of what could happen:

(a) As of the end of the war, we will have a large number of minesweepers fully equipped to cope with any known type of mine at that time. Decision may be reached to retain a number of them in full commission for continued development of the art and to decommission the remainder. If the development of a new type of mine becomes known and if a counter to it is discovered through research, would it be sound to do nothing about the minesweepers out of commission, if the counter, once started, would take, say, two years to bring into production and install on all vessels concerned?

(b) A new and revolutionary anti-aircraft weapon may be discovered. This might be a matter of a new gun or a matter of tactics which requires a larger number or rearrangement of the guns already available. Would it be sound to do nothing until war threatens when the improvement may require months to produce and then more months to install in all ships? In the case visualized, it is considered that it would be foolhardy and futile to expect any vessel to meet an air attack without the new facility.

Decision having been reached as to making the improvement and as to what vessels it should apply, a plan must be developed for production and for installation. The time element in the plan should be capable of telescoping as much as possible. The international situation will lead to decision as to whether normal hours of work and routine availabilities of vessels will permit completion of the job in time, or whether greater acceleration is necessary. Once the plan is made, a change in the overall situation

may force a speed-up in accomplishment, or later research or development may dictate a slow-down or complete stoppage.

In making the plan for accomplishment of the improvement which research has made available, it should be divided into procurement and assembly of the necessary material and installation. The cost estimates for inclusion in the budget can be divided in the same way and the necessary appropriation spread over a reasonably long time. It is not possible to instantaneously produce a large number of certain kinds of material, nor is it practicable to make an entire fleet available for work at one time. It is foolhardy and improvident to immobilize money in material which is not to be used for some time in the future. It is more foolhardy to get caught in an emergency with superb plans for bringing ships up to modernness but with the need for waiting months or years to get the necessary material to do the job.

A return after the war to a routine overhaul schedule for all ships will permit keying this schedule into both procurement of the material and making the installation or alteration. If the material can be produced and delivered at the overhaul point at a rate just sufficient to meet the overhaul schedule for which it is required plus an additional amount just sufficient to fill in work load by working on vessels out of commission or in reserve, and if the overhaul schedule is adhered to, the best all-around economic status will be achieved.

The ships in reserve which were mentioned are a very important element in the plan. They will provide a work load leveler in each overhaul yard which is an economic advantage not only to the yard and hence the government, but to the individual laborer as well. Of far greater importance, the ships in reserve will be maintained in the most up-to-date condition which is practicable within their basic design.

At all times the productive capacity for Naval research products must be under survey so that a minimum of time will be lost if it becomes necessary to accelerate the application rate due to emergency. If a war emergency comes, all approved projects on all ships must be completed as closely to instantaneously as practical and the Navy must be in a position to take care of large numbers of ships to be acquired and converted and additional ones to be put under construction. With good planning, this can

be effectively accomplished during peacetime at no cost except the overhead of maintaining the planning group.

The same plan which has been discussed for vessels is, of course, generally applicable to planes, and shore stations. For the complete Navy, the three material elements: vessels, plans, and shore stations, are the only true *end products.* There are five major groups of components which fit into all three. These can best be described by their popular names: ordnance; electronics; electrical; fuels, lubricants and chemicals; and metals. The parallelism between these five as to their general applicability to the three Naval end products requires that they be given separate treatment in the research organization. Unfortunately, the organization of the Navy Department does not give them all a parallel status. That is another subject, not directly pertinent here. However, for laying out an effective organization to foster research from germination of ideas through full application to a naval end product, it is desirable to consider that all electronics and electrical, and fuels and lubricants, and metals design and specification matters are centralized just as all ordnance matters are today.

For all other fields of scientific research, or of applied research, it is believed that the pertinance to one of the three end products is singular enough to allot responsibility for them to the activity controlling the end products concerned.

What has been said so far is mostly words. What must now be covered is a practical organization whose sole aim is to keep research and its application alive and consonant with a supermodern Navy, and to do it in such a way that Congress and the general public will be eager to accept the necessary expenditure of funds.

Naturally, the Secretary of the Navy is the head of Naval Research. The more he is an actual and active head rather than a nominal one, the better will be the end results. Next to the Secretary, comes a Director of basic research who should report directly to the Secretary. He should have sufficient staff to do the actual work of coordinating, supervising and apportioning basic research. This group must be familiar with the efforts of all scientists and inventors, and with the requirements of the Navy. Its function is to keep abreast of scientific advances and to keep the Bureaus advised and to keep abreast of the Navy's

requirements, and take necessary steps to foster or to accomplish basic research.

The Director's responsibility in regard to inventions is merely to know what is being done and to advise the responsible Bureau of anything which appears to be pertinent to its field. He would then keep track, for the Secretary's information, of the use to which the Bureaus put the information received.

Also under the Secretary, but separated from him by the Commander-in-Chief, U. S. Fleet, would be a Director of Research Application. In the present organization, this would fit into the Office of the Chief of Naval Operations. This Director, with necessary staff, would maintain intimate contact with the vessels, planes, and shore stations of the Navy; would analyze all of their performances; would analyze all available information about other navies; and would be continually aware of the areas in which improvement of our own end products is necessary or desirable and in what particulars other navies have apparently outstripped us. This office should, in its analysis of our own operations, receive all reports of gunnery, engineering and communication performance and of all derangements.

The Director of Research Application would make the results of his analyses known to the responsible Bureau—Ships, Aeronautics, or Yards and Docks. He would keep track of progress in finding answers to problems presented. Possibly, of greatest importance, for every improvement brought to practical realization by one of the Bureaus, he would be responsible for making the decision, first: that it shall be applied and second: to what units it shall be applied. Then he should approve the necessary budget for final approval by Cominch and the Secretary. This budget which is the meat of the whole research proposition should include the requirements of both Directors and all Bureaus for carrying out the responsibilities of each from basic laboratory research until every approved research product is installed in every vessel, plane, or shore station for which it is approved.

The Bureaus of Ships, Aeronautics, and Yards and Docks would receive the results of analyses from the Director of Research Application; would receive suggestions from naval personnel pertinent to material under the cognizance of the Bureau, and would, itself, analyze these. The result of the analyses would be a request on the Director of Basic Research for infor-

mation or help, or on one of the intermediate product Bureaus for a development, or the initiation of a specific development itself.

As suggested above, the intermediate product Bureaus would be five—Ordnance; Electronics; Electrical; Fuels, Lubricants and Chemicals; and Metals. Under the present organization, it would seem possible to consider the Radio Division of the Bureau of Ships with the Chief of the Bureau of Ships as Head, as the Electronics Bureau, and the Petroleum Section of the Bureau of Ships with the Chief of the Bureau of Ships as Head as the Fuels, Lubricants, and Chemical Bureau. It would be better, until an organizational change is made, to forget the separate Bureaus for Electrical and for Metals, to have these subjects split among the other Bureaus, and to give the Director of Basic Research the additional function of coordinating the efforts of all in these two fields. This can be accomplished effectively but the more ideal set-up would appear to be the establishment of separate activities coordinate with the other intermediate products activities.

Most of the information distributed by the Director of Basic Research would go to the intermediate products Bureaus. These Bureaus would be responsible for picking up the idea at whatever stage it had reached and carrying on the development until it was ready to present to one or more of the end-product Bureaus for final consideration, development and test. In the usual case, the intermediate products Bureau would turn over a working model for test. From this point onward any further development or application would be the responsibility of the end-product Bureau.

Each Bureau would maintain and operate the necessary laboratories and shops to carry on its segment of the work. In addition, both the Bureau of Ships and Aeronautics would have assigned to it active useful ships or planes and dirigibles which are under its full control for the trial of any material or device which it wants to test for applicability. The same thing is not exactly applicable to the Bureau of Yards and Docks but that Bureau must have equivalent opportunity to test its end product research.

Naturally, to place this proposal into full effect, requires some arbitrary delineation of responsibilities. It is necessary that these arbitrary lines be established and accepted. All hands concerned

must realize that there is only one goal and that the primary purpose of each individual is *service* to that goal—the best Navy which science can produce.

The outlined organization calls for little modification in what the Navy now has. The most important thing to be accepted and preached by all hands is that research is of no direct benefit to the Navy unless its fruits are available to Fleet Commanders in the units under their command. A new device which would improve a vessels opportunity to overcome an adversary cannot be installed if the vessel is unexpectedly sunk in an unannounced encounter. Had the improvement been made when it might have been, it could have been the other fellow's ship that sank.

GALVANIZING

By Commander W. H. Spowers, Jr., U.S.N.R.

Some Principles of Zinc Coating.

One of the most persistent problems which confront the worker in iron and steel is the prevention of corrosion. We cannot rid ourselves of the agents which effect the corrosion of iron without, at the same time, ridding ourselves of the agents which are essential to life itself.

Air is indispensable both to human respiration and for the formation of rust and other oxides, for which it supplies the oxygen; moisture is necessary for the formation of clouds, which makes the earth fertile, and it also supplies the medium in which rusting takes place and hydrates the oxide; carbon dioxide is an animal by-product and a raw material for the vegetable world, and the exchange of carbon dioxide and oxygen, which is continually taking place between the animal and the vegetable kingdoms, is of vital importance. Then, on the other hand, rust is not readily formed, if at all, unless there is an acid present, and the acid which is most universally distributed is carbonic acid, or hydrated carbon dioxide.

There is, therefore, a close relationship between the processes of living and rusting, but, while human beings make up for the rusting or decaying of their tissues by nutrition, it has not yet been discovered how to feed or regenerate iron, and until such a discovery is made we are compelled to take our cue from the ancient Egyptians and resort to embalming.

There are two general ways of embalming iron as to prevent its decomposition, which might be called, respectively the metallic and non-metallic methods. In the non-metallic method the articles are coated with an organic substance, usually oil or varnish, the efficiency of which depends on its being more or less air-tight. When coloring matter is added to the oil it becomes a paint, but

Quotations from "Hot Dip Galvanizing Practice" by W. H. Spowers, Jr.—Penton Publishing Company, Cleveland, Ohio.

I understand from authorities on the subject, that a varnish free from pigments is preferable to anything else.

The metallic method consists of coating the iron with some other metal, and it is this method in which we are interested. Iron rusts less easily than does steel. This is perhaps due to steel being a very composite material. In the iron which forms a bulk of its composition, are dissolved or immersed a great variety of other substances. Some of these are simple such as carbides, sulphides, phosphides and silicides. The carbon compounds are very numerous and diversified being due to the different heat treatments. The best known are cementite, pearlite, and martensite. Just as variety is to some people the spice of living, so is heterogeneous composition the spice of rusting, in the present instance at any rate.

It is difficult for many persons to understand why zinc is the best rust preventive for iron and steel, and they believe it is on account of its cheapness that it is so extensively used. They have an idea that lead would answer for better, and as it is more non-corrosive than zinc would protect the iron better. But the softness and difficulty of application react against the use of lead.

The very fact that zinc is a corrosive metal does not effect its properties when applied as a coating to iron or steel. Indeed, if it did not corrode, it would not be of value for such a purpose. When iron or steel, which has been coated with zinc, is exposed to the atmosphere, a galvanic action is set up, although of course, extremely slight. Any two dissimilar metals form a galvanic couple, but as zinc is the most electro-positive metal, the galvanic action between the zinc and iron is as great as could be obtained when iron is used for one of the metals composing the couple.

The result is, therefore, that with the slight galvanic action set up on galvanized iron or steel, when exposed to the atmosphere, a corrosion takes place. Did it not follow, then, there would be no protection. In this case the zinc, being the electro-positive metal, suffers corrosion at the expense of the electro-negative metal, iron. The effect is that the corrosion goes on with the zinc exclusively and the iron is not corroded at all, provided any zinc is left on it.

The reason for the protection of iron or steel by a zinc coating is, therefore, on account of the fact that the zinc corrodes at the expense of the iron or steel by the galvanic action set up. Zinc

however, when exposed to the air, does not corrode rapidly or deeply, but in fact, very lightly. This property is of great value, as the zinc coating does not corrode rapidly, even with the galvanic action set up, so that it lasts for a far greater length of time than would naturally be expected. The very fact, however, that the zinc corrodes at the expense of the iron is all that is necessary to protect the iron or steel, even though it be extremely slight.

Other metals like lead or tin, on account of their not being electro-positive to iron do not act like zinc. They act simply as a covering, like paint or varnish, and if portions of the iron happen to be exposed, even such as a pinhole, the iron begins to corrode. With a zinc coating, however, this will not take place.

The process of galvanizing is first cleaning. The steel is immersed in diluted sulphuric acid, until all the dirt, rust or oxide is removed. Then it is thoroughly washed, dipped in a fluxing acid and brought to the galvanizing kettle. Upon the thoroughness of the cleaning process depends to a great extent the successful results. The work must be presented to the galvanizer as virgin metal uncontaminated by any foreign substance.

The work is slowly immersed in the zinc and permitted to remain until it "thaws out", or comes to the same temperature as the zinc. It is then slowly removed.

PICKLING.

Figure 1 shows the building housing the galvanizing shop at the Navy Yard, Portsmouth, N. H. This building is 60 feet wide and 200 feet long. Fifty feet of the far end houses the sand-blasting equipment and 150 feet at the near end houses the pickling and galvanizing equipment.

By reference to Figure 2 it will be noted that all equipment has been placed for straight line technique in such manner that the work will travel in a straight line, to, through and out of the pickling equipment and galvanizing kettle.

As seen in Figure 2 the first tub contains caustic soda; the second and third, Sulphuric Acid; the fourth, running water; and the fifth, the flux wash.

The technique of operation in the Sulphuric tank is as follows: This tank should be heated and maintained at a strength of from 8 to 10 per cent, percentage by weight, at a temperature of approximately 150 degrees F. and included in this tank an

FIGURE 1.

FIGURE 2.

FIGURE 2.

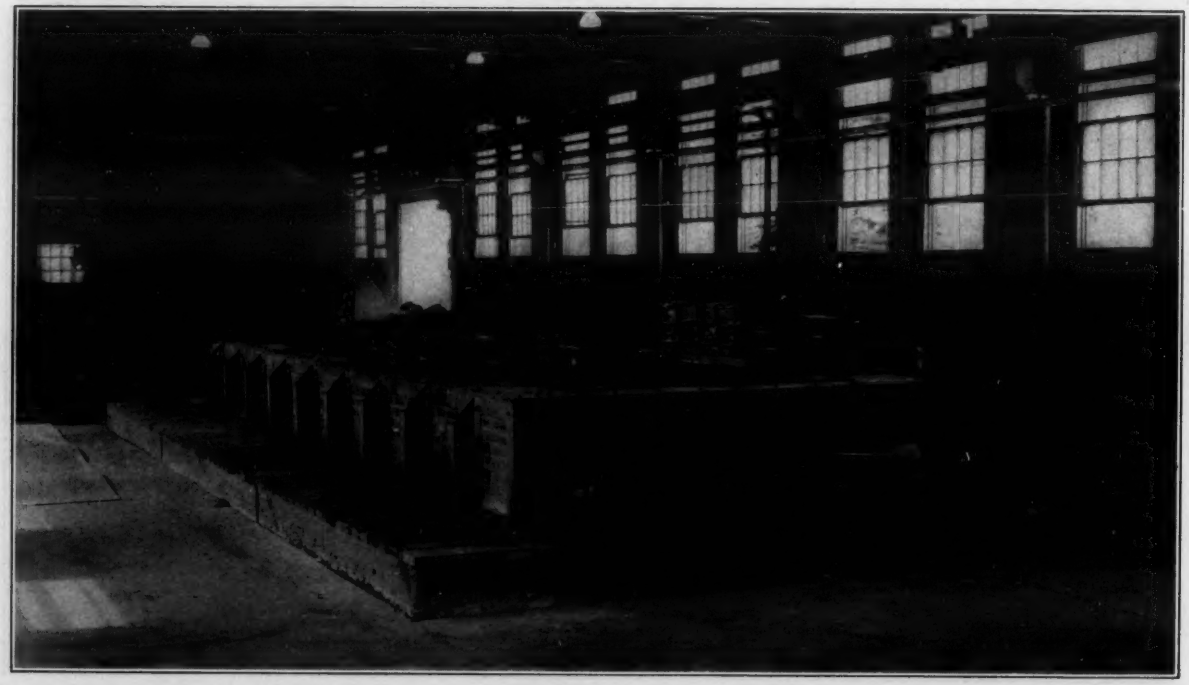


FIGURE 3.

FIGURE 4.

inhibitor for economical operation for the protection of the surface of the steel against over-pickling and the elimination of acid fumes.

Additions of free acid are made to this tank continuously to maintain the desired strength until such a time as the iron concentration reaches 4 per cent when no further additions are made. At this point the temperature of the bath is raised somewhat for a short period of time without further additions of acid so that when the tank is emptied it will be rid of free acid.

Appendix I outlines in detail a study on Sulphuric Acid cleaning.

If it is found necessary to strip any material for regalvanizing, such pieces are reserved until the time arrives for dumping the Sulphuric tank. The temperature is then raised slightly and these pieces immersed for stripping. The action resulting from this process will kill the acid so that it cannot be used for further pickling. Therefore, any work which needs be stripped should be so stripped just prior to the release of the acid.

Stripping of the work need only be done if the work has been galvanized for a sufficient length of time to have oxidized heavily, or if the work has originally been incompletely cleaned. Regalvanizing work just done, because of improper surface coating, needs simply dipping in the flux tank prior to regalvanizing.

Water.

Next in line is the water rinse tank. This tank is maintained full of clear clean running water and is a most important step in the cleaning operation because it must remove from the surface of the work all the iron salts resulting from the pickling action of the Sulphuric Acid and present to the flux wash tank material in an absolutely clean condition. This tank may be maintained hot or cold as the exigencies of the technique may require.

Flux Wash.

This last tub contains a solution of zinc salts known as No. 20 Galvanizing Flux. This is a neutral flux that will not contaminate and form dross in the galvanizing kettle as does a muriatic acid flux wash.

The use of neutral fluxes for galvanizing is becoming very popular where the proper technique is thoroughly understood.

Proper preparation and use of this new flux is a relatively simple operation and one which will effect, in almost every case, great economies in dross losses in the galvanizing bath. In the use of this flux, wherever the operation is sufficiently continuous, no volatile flux additions to the top of the bath such as sal ammoniac or zinc ammonium chloride is necessary. The carryover of No. 20 from the flux wash tank will maintain any required surface volatile flux blanket desired.

It must be understood that the greatest manufacturer of dross in galvanizing is the salts resulting from the pickling acid. These salts are high in iron and are of such a nature as to rapidly contaminate the fluid zinc and turn it to dross. As a matter of fact, fully 50 per cent of the dross made in the galvanizing operation, where active fluxes are used, is because of these iron salts; 25 per cent of the dross manufactured in many instances, comes from the boiling of the dross because of too low firing, too intense or over-firing of the kettle resulting in a boiling effect in the zinc; 15 per cent of the dross manufactured comes from the work itself passing through the zinc, and 10 per cent from the contamination from the sides of the kettle.

It can then be readily seen that if the iron salts resulting from the pickling action are eliminated the dross consumption will be very materially reduced.

These iron salts effect also a widening or thickening of the interlining alloys between the zinc coating and the base iron which results in an improper bond between the zinc and iron, producing an easily flaked or broken coating.

In the use of this neutral flux a very effective reduction in the width of these alloy layers has been found because of the elimination of these iron salts.

All material on which a tight ductile bond is desired should be ordered *fully silicon killed*. This is one of the most important items to be remembered in obtaining tight bond. No aluminum should be used at the open hearth. This demand will probably meet with some resistance from the open-hearth department, but if the desired result is to be obtained it must be insisted upon. The day is past, when any old stock, which cannot be used elsewhere, can be shipped to the galvanizer.

Details for the use of No. 20 Flux are as follows:

In the first place, the material after pickling must be well washed to remove the iron salts resulting from the pickle. The work must then be promptly immersed in the flux bath before there is a chance for it to rust or dry.

The flux bath shold be prepared as follows:

A solution of No. 20 crystals should be made in this manner: Figure the gallonage capacity of the tub and add 3 pounds of No. 20 per gallon of water. Then add sufficient No. 20 to bring the reading on a Baume Hydrometer to 28 at 150 degrees F. This temperature and strength should be maintained by additions of water and No. 20.

It will be found that very nearly sufficient of this flux will carry over on the work to maintain a volatile flux on the top of the bath. However, in some cases because of the interrupted nature of the work some small additions of No. 20 will have to be made on the bath.

Effect of Alloy Layers on Bonding.

In every zinc coating operation there forms between the base metal and the pure zinc layer a series of alloy layers. Microphotographs of the zinc coatings show three of these distinct layers. The one nearest the base metal is very high in iron, the middle one still high in iron but somewhat less, and the outer layer considerable lower in iron. These layers, it has been shown, are present in every coating of zinc even though the immersion be for so short a period as 1/20th of a second. These alloy layers are extremely brittle and will fracture the zinc coat upon bending very easily.

The particular type of structure of the alloy layers is of importance also. Microphotographic examination of these structures leads to the definite conclusion that the layers must be applied in such a manner as to reveal an even or smooth line of demarcation. If the alloy layers prove to be irregular or tree-like in appearance this irregularity will invariably lead to an easy fracture. The method of introduction of the work into the zinc has much to do with this and is an important reason for the use of a neutral flux as a flux wash.

It is also invariably the case that the thinner the alloy layers the more perfect will be the bond between the pure zinc coating

and the base metal. The procedure of producing thin alloy layers on zinc coatings is as follows:

1. The work must be free from iron salts at the time of immersion in the zinc.
2. The work after being washed should be protected from any oxidization by the use of a neutral flux.
3. This flux must be protected from the burning which results from sudden quench in hot bare spelter by the use of a proper introducing agent (provided for in No. 20 flux).
4. The work must be immersed for as short a time as is possible to effect the weight of coating desired and at as low a temperature as is possible.
5. The work must be galvanized in pure zinc absolutely uncontaminated by floating dross.

Galvanizing.

It is important that all galvanizing be done in clear zinc, uncontaminated in any way with dross, and for this purpose it is recommended that the galvanizing kettle be heated on the sides well above a determined line which may be the part allotted for the accumulation of zinc dross.

Formation of Zinc Dross.

Zinc dross consists primarily of pure zinc which has been contaminated by a small percentage of iron. This iron comes from, to a small degree, off the sides of the kettle, to a small degree from the work which has been immersed, and to a substantial degree from the iron salts produced by an active or improper flux. There is, however, another item of dross formation which is very important because of its influence on the interlining layers, tightness of bond, and life of equipment. The steel kettle in which the zinc is melted must not be placed in the furnace in such a way as to restrict to a limited area the heat application. Likewise the kettles must not be installed in a furnace in which the heat is applied from below or too low a point on the sides of the kettle so as to effect a boiling action in the dross. It is also important in any molten metal operation of this kind that sufficient capacity be provided for in the body of the metal itself so that there is not too rapid a transfer of heat.

As the zinc becomes contaminated by iron it settles of its own

gravity to the bottom of the kettle and in order to galvanize in pure zinc the furnace must be so designed as to not only allow but to assist this natural precipitation of contaminated zinc to the bottom of the kettle without interference.

By applying heat to the bottom of the kettle or producing a heat input over too restricted an area, there will be an interference with the natural settling of the dross, with the result that it floats the dross again and places back upon the work a considerable quantity of drossy zinc. This drossy zinc affects materially the formation of the alloy layers and places upon the work a coating of poor quality.

Accepting then, the fact that the heat should be applied constantly and evenly over a wide area of the sides of the kettle and not from the bottom or concentrated upon too restricted an area, the designer must not stop there. The greatest amount of heat, as a matter of fact, should be applied to the upper portion of the sidewalls of the kettle where the greatest heat is taken out. Less heat at the lower portions and little or no heat below a determined line allowed for the accumulation of zinc dross.

In this connection it may be noted that at the Navy Yard, Norfolk, Virginia a conversion from a small under fired, under capacitied galvanizing kettle using an active flux wash and resulting in a 59 per cent dross loss over pure zinc added, to a furnace of proper design and using neutral flux resulted in a reduction in dross loss to 14 per cent. In other words, out of every 100 pounds of pure zinc added to the old furnace 59 pounds had to be dug out of the bottom of the furnace as dross and sold at a loss, but in the new furnace only 14 pounds was lost.

Figure 3 pictures a correctly designed galvanizing setting. The steel kettle itself is built of 1¼ inch fire box steel plate and is of welded construction. It is 20 feet long 44 inches wide and 48 inches deep and holds approximately 140,000 pounds of pure zinc.

The furnace surrounding the kettle (Figure 4) is lined with 4½ inch first quality firebrick, the insulation is of 2½ inch 1600 degrees F. insulating brick and the casing is 4 inch of standard red brick reinforced with structural steel shapes.

Firing is accomplished by a series of tunnel type impact burners designed for Propane gas at 6 to 7 inch 10 C. pressure. Air for combustion is supplied by a #316-E2-7-½ blower complete with motor and starter to supply a constant pressure at 1 pound.

Temperature control is accomplished by two-zone automatic equipment consisting of 2-Wheelco #221 Indicating and Controlling Pyrometers hooked to two Iron Constantin Angle Type Thermocouples encased in special protecting tubes.

This furnace controlled in this manner will maintain the zinc at 860 degrees F. under any reasonable conditions.

The equipment thus outlined has been in complete operation since 1 February 1944 and up to 1 July 1944 (5 months) had galvanized over 2,000,000 pounds of work with a complement of 13 men. The work was classified as follows:

		Pounds
1.	Fabricated sheet metal work	170,519
2.	Plates and shapes, both fabricated and plain	1,519,197
3.	Nuts, bolts, studs and forgings	225,773
4.	Pipe, bent and cut to shapes	153,266
	Total	2,068,773

Centrifugal Galvanizing.

One of the most successful and satisfactory features of the modern galvanizing plant is the production of high grade centrifugal work through the use of a well designed centrifuge. Figure 4 pictures such equipment in use at the Navy Yard, Portsmouth, N. H.

The centrifuge shown is a Barrett #402G Centrifuge galvanizer. This machine operates at 900 Rpm. and reaches a maximum speed in ten seconds. It receives a 160 pound gross basketful of material every 90 seconds, and throws off in 30 seconds, all excess material from threaded parts that must remain movable.

Besides threaded nuts and bolts and various small articles otherwise difficult to handle, much of the work centrifugally galvanized consists of various parts going into the construction of blocks manufactured by the Yard. These parts consist of assemblies of single, double and treble blocks of various sizes from 4 inches to 24 inches all of which contain snatch block fittings, swivel hooks and swivel fork shackles, one to five in number, needing to turn freely after galvanizing.

Formerly a long and expensive hand operation was necessary to free frozen zinc, involving the use of four men to burn, swing

sledge hammers and manipulate with crowbars the movable parts. The result was chipped and burned surfaces and the galvanized coating was nullified. Manhours, oxygen gas and zinc were wasted.

The strict technique of operation in centrifugal galvanizing must be followed.

As will be seen in Figure 4, perforated steel baskets are used as a container for the material. After loading, the baskets are slowly lowered into the zinc through a volatile bath blanket. One basket follows the other to the out-go end.

The volatile blanket is then skimmed back and the basket quickly swings to the centrifugal. Only the shortest possible time must be consumed between the exit of the basket from the zinc to the full speed of the centrifugal so as to permit little or no setting of the zinc before the machine attains full speed.

After completion of the spinning operation the basket is again quickly lifted from the centrifugal and transferred to the tilter shown at the left of Figure 4 where it is upset and the work quenched in water covered with a light film of a good grade of quenching oil.

The installation of modern, adequate galvanizing equipment at various Navy Yards has effected a concrete contribution to efficiency and economy. Rush orders are handled immediately, very urgent materials can be turned out in fifteen or twenty minutes. Large quantities of rush material move to the head of the work list for the day and in no instance do more than a few hours elapse between receipt and delivery.

APPENDIX I

Investigation on Use of Sulphuric Acid for Pickling.

The following investigation was conducted for the purpose of determining the effect of the concentration of sulphuric acid on the time of pickling.

Method of Procedure.

Sheets of 20 gauge standard enameling steel measuring 4 inches by 6 inches were annealed at 1400 degrees F. for 2 minutes in an electric furnace. Three samples of each were then pickled in

sulphuric acid of the following concentration: 1-15 per cent inclusive, 20 per cent, 25 per cent, 30 per cent, 40 per cent and 50 per cent, and at temperatures 77 degrees, 105 degrees, 120 degrees, 150 degrees, and 180 degrees F.

The time required for complete removal of the oxide by the action of the acid itself was recorded.

Results.

The average results of three different samples in each test follows:———Temperature of Annealing———1400 degrees F.

Strength of Sulphuric Acid (Per cent by Wgt.)	Time required to Pickle at Temperatures *77F.* Min.	*105F.* Min.	*120F.* Min.-Sec.	*150F.* Min.-Sec.	*180F.* Min.-Sec.
1.....	80	24	14	8	2-30
2.....	45	15	8	4-30	1-30
3.....	40	15	5	4	1-30
4.....	35	14	6	3	1-15
5.....	30	13	4	3-30	1-15
6.....	28	12	5	3	1-15
7.....	25	11	4	3	1-15
8.....	22	12	4	2-30	1-15
9.....	20	12	4	2-30	1-15
10.....	20	11	5	2-30	1-10
11.....	20	11	5	2	1
12.....	20	9	5	2	1
13.....	18	8	5	2	0-55
14.....	16	8	4	2	0-45
15.....	15	8	4	1-30	0-45
20.....	9	7	5	1-30	0-30
25.....	8	6	4	1-30	0-25
30.....	12	7	4	1-30	0-20
40.....	13	6	5-30	2	1
50.....	30	18	17	25	8

Conclusion.

At 77 degrees F. the acid concentrations requiring the least time for pickling are between 20-40 per cent. These concentrations pickle in 13 minutes or lower. The 25 per cent solution at this temperature pickles in the quickest time which is 8 minutes.

The 50 per cent acid gave a rapid rise in the time of pickling increasing from 13 minutes at 40 per cent to 30 minutes at 50 per cent strength.

At 105 degrees F. the acid concentrations requiring the least time are those between 12 and 40 per cent which require 9 minutes or less for pickling.

The 25 per cent solution again pickles in the least time which is 6 minutes. With 50 per cent acid the time of pickling increases to 18 minutes.

At 120 degrees F. the best concentration appears to be between 8 and 30 per cent. The time of pickling being 5 minutes or lower. The best practical concentration at this temperature appears to be about 5 per cent which requires 4 minutes time for pickling. Above 30 per cent concentration the time of pickling begins to increase.

At 150 degrees F. the most rapid acting concentrations are from 4-40 per cent inclusive, all of which pickle in 3½ minutes or less. With concentrations above 30 per cent a black scum was left on the sheets.

At 180 degrees F. the time for pickling at all concentrations was 2½ minutes or lower except in the 50 per cent concentration where the time required for pickling greatly increased as was the case with all other concentrations. At 30 per cent and higher concentrations scumming occurred as at 150 degrees F. Much fuming occurred at all concentrations at this temperature which rendered such temperature undesirable.

The time required for pickling at all concentrations of 40 per cent or lower is rapidly diminished with increase in temperature especially up to 120 degrees F.

The time of pickling is accelerated much more by rise in temperature than by increase in acid concentration, i.e. at 120 degrees F. 5 per cent acid pickles just as rapidly at all concentrations up through 30 per cent, whereas at room temperature only between 20-25 per cent acid concentration is there any proximity in pickling time.

The increased time of pickling above 40 per cent acid strength is due to the decreased ionization and probably partially due also to the oxidizing effect of the hot concentrated sulphuric acid both of which retard the solution of iron and the formation of hydrogen gas which forces the scale off the plate. That the hot

concentrated acid has an oxidizing effect is shown by the change of color of the scale to a bright red in the 40 to 50 per cent concentration at 180 degrees F.

The acids above 30 per cent concentration at 150 and 180 degrees F. left a scum on the ware which is objectionable, so that a more diluted acid is desirable for pickling.

The best temperature for the most rapid and practical pickling appears to be between 120-150 degrees F. Below 120 degrees the time of pickling is greatly increased and at 180 degrees the fumes are excessive.

The best, most practical and most economical concentration appears to be 5 per cent sulphuric acid from 120-150 degrees F.

Slight fluctuations on the curves in the time required for pickling need not be considered seriously since the end point is not very sharp.

The loss in weight of sheets in the acid showed that pickling time increased more with the per cent of steel dissolved than it did with increase of acid concentration, e.g. sheets at 77 degrees F. lost 3.2 per cent by weight with 1 per cent acid requiring 80 minutes; at 6 per cent acid concentration and 28 minutes time, the loss was 2.5 per cent; at 10 per cent acid concentration and 20 minutes time, the loss in weight was 2.1 per cent.

A test showed that a piece of steel which has been annealed four times required 10 per cent more time to pickle at room temperature after the fourth annealing than it did to pickle the same after the first annealing.

A NOMOGRAM FOR SPRAYER PLATES.

By Fred J. Wiegand *

Mechanical pressure-atomizing fuel oil burners require an atomizing tip or sprayer plate to break up the fuel into small particles. In the case of the one-piece sprayer plate as used in the Navy, the fuel to the furnace is supplied under pressure through tangential slots or grooves into one end of a semi-spherical chamber (whirling chamber) at the other end of which there is an exit orifice. If the ratio of total slot area to the orifice area is 0.8, the sprayer plate is known as an 08 ratio plate. Each sprayer is designated by four digits, the first two indicating the twist drill size used in making the orifice and the last two the actual ratio multiplied by ten.

The quantity of fuel oil which can be atomized by the sprayer plate is affected by the total slot area and by the area of the orifice; the angle of spray is determined by the ratio between these areas. In the design, manufacture, and test of sprayer plates, therefore, it often becomes necessary to determine the size of the tangential slots. This is done at present by employing the following formula:

$$X = \sqrt{\frac{AR}{N} + 0.00004292}$$, in which

X = side of square slot in inches
A = area of orifice in square inches
R = actual ratio of total slot area to orifice area
N = number of slots
0.00004292 = a constant to compensate for filleted corners of 0.010 inch radius

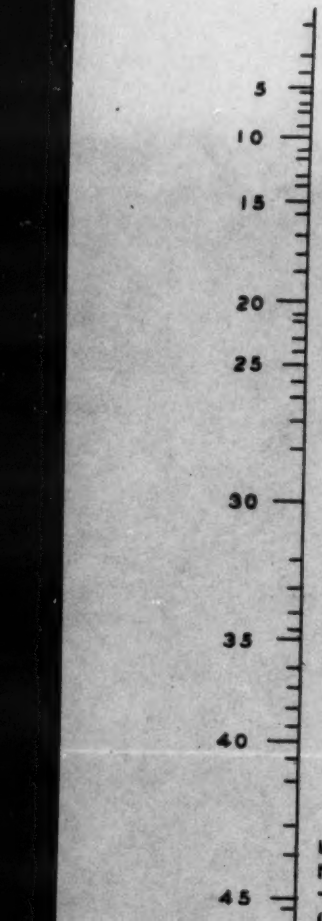
It was considered that a parallel-line nomogram could readily be constructed to perform the above mathematical operations and furnish immediately and accurately, without any computation, the solution of this equation. This was done but, in order to

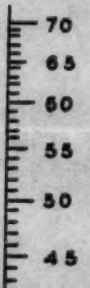
* Associate Mechanical Engineer, Naval Boiler and Turbine Laboratory.

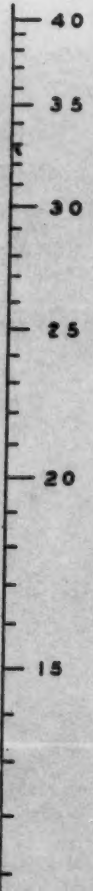
avoid the use of a turning scale involving two operations in using the graph, the three charts here shown were made for solution of the equation with N as a constant in each case. These nomograms should serve for all ordinary purposes as production sprayer plates for Naval use are made only with 3, 4, or 6 slots.

There are usually several different sets of values that will satisfy the above formula but one of these combinations is likely to meet the specified requirements better than the others. By use of these charts the sprayer plate designer can promptly determine what are the possible combinations of values and from them select the one best suited to his purpose. It can be seen at a glance whether or not the slot dimension of any proposed sprayer size would be so small that the slot would tend to clog quickly, or so large that efficient atomization of the fuel oil would be lost. Since the total slot area is fixed for any particular sprayer plate size rather than the area of an individual slot, the designer could easily see how many slots a specific size sprayer should have. Experiment has shown that the optimum width of slot is anywhere between 0.030 inch and 0.055 inch. These are only approximate limits and should not be rigidly adhered to if other design factors would be adversely affected thereby. For plates of high capacity it would be better in some cases to hold the slot width at 0.055 inch and make the depth greater than this rather than to increase the number of slots in order to hold to the conventional square cross-section. Interference with the whirling chamber is the controlling factor in such cases. It it hoped that the subject nomogram will be found useful throughout the Naval service.

3-SLOT SPRAYER PLATES







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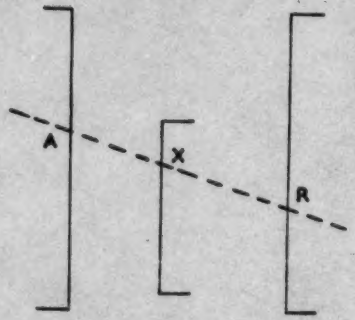


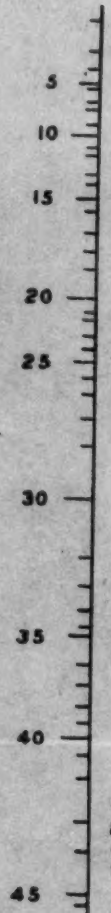
EXAMPLE

To find slot size of 4008 sprayer plate (3 slots)

Drill Size	(A)	40
Ratio	(R)	08
Size of Slot	(X)	0.045"

RATIO
10
09
08
07
06
05
04
FRED J WIEGAND
SIDE OF SQUARE SLOT - MIL S
50
45
40
35
30
25
20
15
DRILL SIZE
45
50
55
60

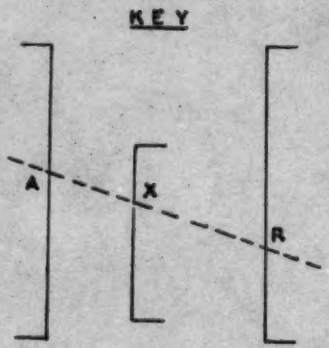
4-SLOT SPRAYER PLATES

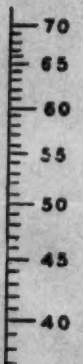


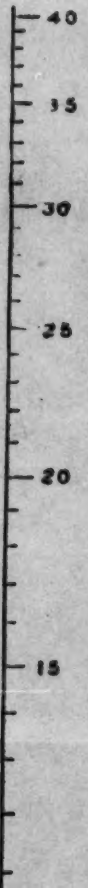
EXAMPLE

To find slot size of 4008 sprayer plate (3 slots)

Drill Size	(A)	40
Ratio	(R)	08
Size of Slot	(X)	0.039"







RATIO

10 09 08 07 06 05 04

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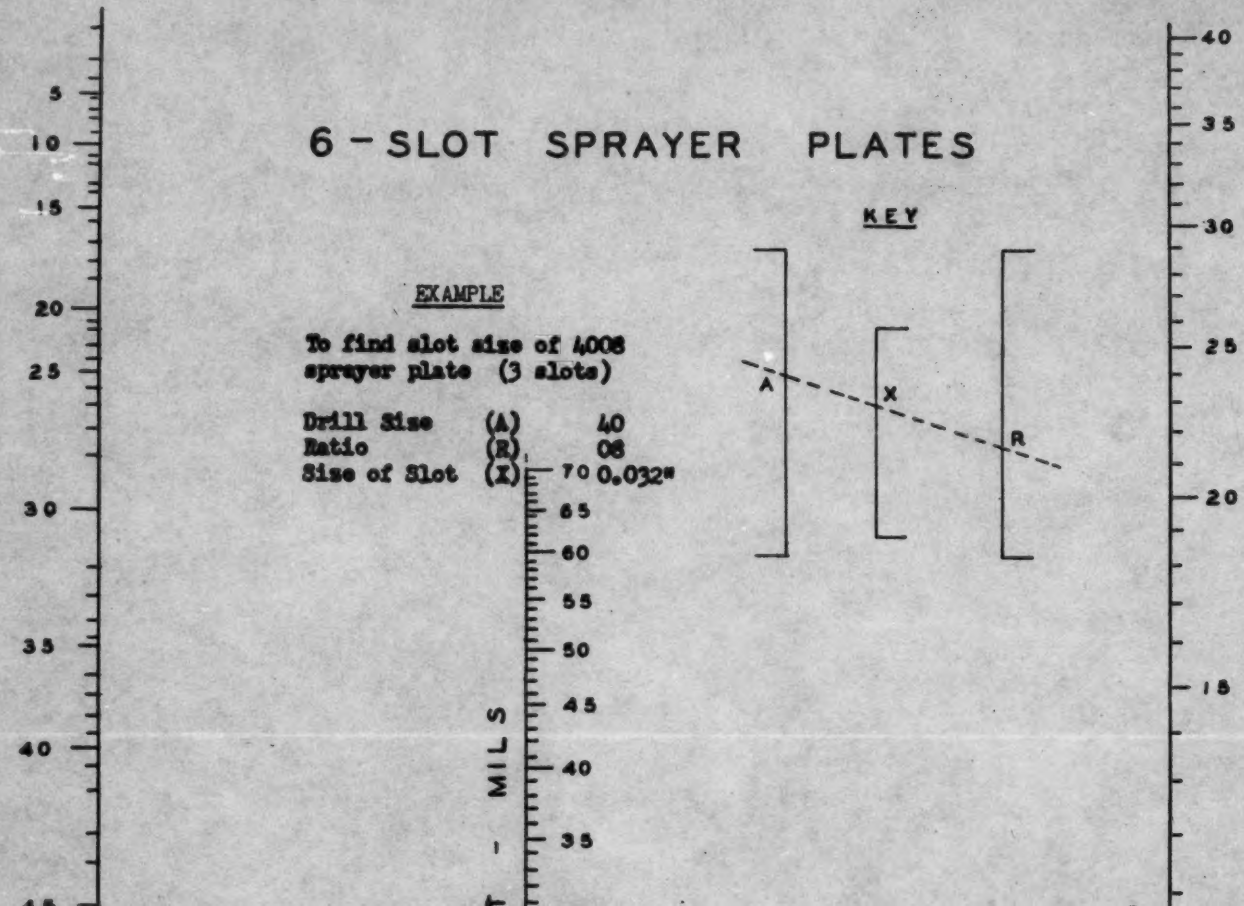
SIDE OF SQUARE SLOT -

45 40 35 30 25 20 15

DRILL SIZE

45 50 55 60

6 - SLOT SPRAYER PLATES



FRED J WIEGAND

NOTES.

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—The Nautical Gazette, November, 1944.

PROPELLING MACHINERY FOR VICTORY SHIPS.

Propelling machinery of the United States Maritime Commission AP-2 and AP-3 designs of "Victory" ships is described in this article, reprinted from the October, 1944, issue of the Shipbuilder and Marine Engine-Builder.

The arrangement of the machinery spaces in the two designs of "Victory" ship, AP-3 and AP-2, is indicated by the drawings reproduced on Plate V. The propelling installation consists of a cross-compound, double-reduction geared-turbine unit, steam being supplied by two cross-drum, single-pass' water-tube boilers of the sectional-header type, arranged for oil-firing. As wil' be seen, boilers and turbines are located in a common compartment.

Main Turbines and Gearing.

The propelling installation of the AP-3 "Victory" ship has a normal rating of 8500 Shp. at a propeller speed of 85 Rpm., when operating with steam at 440 pounds per square inch pressure and 740 degrees F. temperature at the steam-strainer inlet, and exhausting at 28½ inches vacuum.

The set consists of an eight-stage Hp. turbine (6159 Rpm.) and an eight-stage Lp. turbine (3509 Rpm.), connected through flexible couplings to the reduction gearing, and designed to deliver approximately equal power to their respective pinions.

Steam is admitted at the forward end of the Hp. turbine, flows aft to the cross-over connection and forward through the Lp. turbine, exhausting downwards to the athwartship condenser.

The astern turbine, located in the exhaust end of the Lp. casing, has two stages, the first wheel having two rows and the second one row of buckets.

The casings are of steel, and are divided at the horizontal center-line. The inter-stage nozzle diaphragms are held in recesses machined in the casings, and are split at the horizontal joints, so that the upper halves of the diaphragms may be lifted with the upper halves of the casings.

The rotors are machined from solid-steel forgings. All rotor blading is of corrosion-resisting alloy, and the blading is fitted with shroud bands of the same material.

The Hp. and Lp. ahead turbines are designed to deliver approximately equal power to the respective pinions.

All gearwheels and pinions are of double-helical construction, the pinions being of nickel steel.

The welded-steel casing which encloses the rotating elements of the gear unit is divided into several sections, with horizontal divisions at the shaft center-lines. A base section supports the low-speed gear and main thrust bearing, and an intermediate section supports the high-speed gears and low-speed pinions. Individual covers are provided for the low-speed gear, the two low-speed pinions and the two high-speed pinions.

The 33-inch pivoted segmental-type main thrust bearing is located in a housing integral with the lower section of the main gear casing. The bearing has six ahead and six astern shoes, individual shoes being interconnected by levelling plates to obtain uniform bearing for all shoes.

In the AP-2 "Victory" ships, the propelling unit consists of double-reduction, cross-compound turbines developing 6000 Shp. (normal rating) at a propeller speed of 100 Rpm. Other data are given in Table I.

Some sacrifice of propeller and turbine efficiency was accepted in order to secure a small, simple, compact unit lending itself to mass-production and rapid installation. The foundations for all manufacturers' units are the same, except for bolting. All important shipyard piping connections are at the same locations.

The turbines are of the impulse, reaction, or impulse-reaction type, depending upon the manufacturer. The ahead turbine is provided with two hand valves to control the steam flow, giving four nozzle combinations between two-thirds and maximum steam flow.

TABLE I.—NUMERICAL DATA OF AP-2 "VICTORY"-SHIP PROPELLING MACHINERY.

Shp. (at Gear-shaft Coupling)—	
Normal rating, ahead	6000 at 100 Rpm.
Maximum, designed, ahead	6600 at 103 Rpm.
Minimum, astern	2400 at 50 Rpm.

Steam Conditions, etc.—	Normal.	Maximum.
Steam pressure at turbine inlet connection, pounds per square inch	440	465
Steam temperature at turbine inlet connection, degrees F	740	785
Vacuum at turbine exhaust flange, inches mercury	28½	
Extraction from Hp. turbine exhaust at not less than 15 pounds per square inch, pounds per hour	3000	5000
Maximum flow, ahead nozzles, pounds per hour (approximate)	—	54,000
Maximum flow, astern nozzles, pounds per hour (approximate)	—	46,500

Performance—	
Expected non-extraction steam rate at 6000 Shp. and normal steam conditions	7.5 lb. per Shp. per hr.
Cross-compound Turbines—	
The approximate loads and speeds with normal steam conditions at normal power are—	
High-pressure element	3000 Shp. at 5500 Rpm. (nominal).
Low-pressure element	3000 Shp. at 4000 Rpm. (nominal).

The turbine casing, steam chest and other parts in contact with steam are of weldable carbon steel, either in the form of castings or of welded construction.

The rotors, which are of solid forged steel or have individual turbine discs shrunk on the shaft, have been designed so that the calculated critical speed is at least 16 per cent above that corresponding to the maximum designed Shp. The minimum factor of safety employed is 4, based on the ultimate tensile strength of the material at a speed corresponding to the maximum designed Shp. All blading and the Hp. nozzles are of corrosion-resisting steel. The diaphragms, which are divided horizontally, are of steel, with nozzle partitions of corrosion-resisting steel.

The manually-operated ahead and astern maneuvering valves are assembled, with a steam strainer, in a common manifold. The ahead valve is arranged as a speed-limiting governor to throttle the steam supply in the event of the Hp. or Lp. rotor attaining a speed corresponding to a propeller speed of 115 Rpm. The valve is also arranged to cut off the steam supply should the lubricating-oil pressure fall below 6 pounds per square inch at the gearcase inlet. The valve seats and discs are of forged or corrosion-resisting steel, the contacting areas being faced with cobalt-chrome alloy.

Flexible couplings of the gear-tooth type are inserted between the turbine rotor and the high-speed pinions.

The double-reduction gearing is of either articulated or nested type. The gear casings are of cast-steel or welded construction, and are divided so that the bearing and rotor parts are readily accessible. The forward end of the gearcase supports the after end of the turbine casing, and is arranged to

permit removal of the first-reduction pinions without disturbing the turbines and *vice versa*. The lower gearcase is constructed to permit the handling of the completely assembled gear unit.

The pinions are of heat-treated forged steel (Brinell hardness No. 200 to 240). The gearwheels are made from single forgings or castings, or built with forged-steel rims. The rim section, on which the teeth are cut, has a Brinell hardness No. of 160 to 190.

The propeller thrust bearing is of the pivoted, segmental type with solid base rings, and is accommodated in the gearcase. The bearing has a thrust area of 440 square inches in either direction.

Shafting and Propeller.

The line shafting is of forged steel. The bearings are of cast iron, the lower sections being lined with lead-base Babbitt metal. They are of the ring-oiled type, one bearing being fitted for each length of shaft.

The tailshaft is of forged steel, with a composition liner. The stern-tube is of cast iron, fitted at each end with a composition bushing, lined with staves of moulded fabric and bonded with phenolitic resin.

The solid, four-bladed propeller is of manganese bronze, the blades being of aerofoil section.

The dimensions of the shafting and propeller are as stated in Table II.

Table II.—Dimensions of Shafting and Propeller.

	AP-3.	AP-2.
Line-shaft diameter.....	19 inches	16 inches
Propeller-shaft diameter.....	21 inches	18 inches
Propeller diameter.....	20 feet 6 inches	18 feet 3 inches

Lubricating-oil System.

Lubricating oil is drawn from a sump in the inner bottom below the reduction gearing, and is pumped *via* a duplex strainer and oil-cooler to a gravity tank, installed at an appropriate height to maintain the designed oil pressure at the reduction gearing.

There are two lubricating-oil pumps—*viz.*, a vertical rotary motor-driven unit, and a vertical duplex steam-driven stand-by pump. The latter is arranged to pick up the load in case of failure of the motor-driven unit.

The two lubricating-oil coolers (each of sufficient size to deal with all the oil required by the main unit) are of the straight-tube type, the tubes being $\frac{5}{8}$-inch O.D., No. 18 B.W.G., and made of aluminium brass. Each has a capacity of 325 gallons per minute when cooling oil from 130 to 110 degrees F. with sea-water at an inlet temperature of 85 degrees F. Cooling water is supplied by the main circulating pump.

One lubricating-oil purifier, having a capacity of 350 gallons per hour, is installed.

Condensers.

The main condensers of the AP-3 vessels are of the two-pass type (7900 square feet of cooling surface), and are designed to maintain a vacuum of 28½ inches under normal-power conditions when supplied with cooling water at 75 degrees F. The condenser shell is of welded steel, the condenser being supported from the turbine or from bridge girders, depending on the turbine design. The tubes, of aluminium brass, are ¾-inch O.D., and No. 18 B.W.G.

The main circulating pump is of the vertical, single-stage, double-suction, centrifugal type, driven by a 100-Hp. motor, and having a capacity of 13,000 gallons per minute against a total head of 10.9 pounds per square inch at about 630 Rpm.

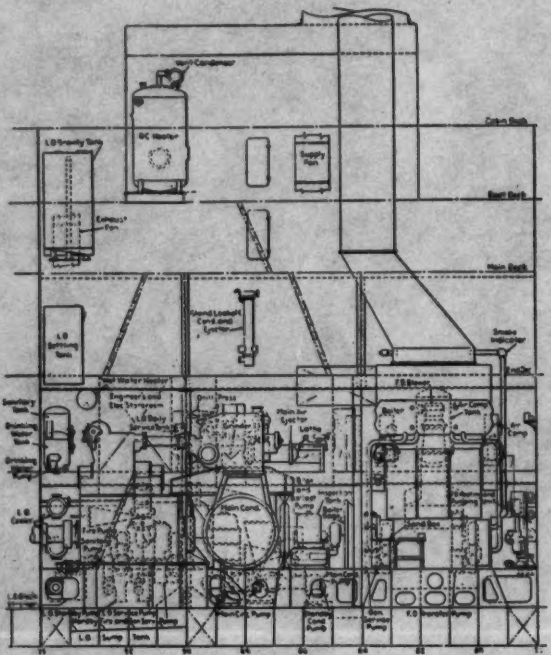
The twin two-stage air ejector is condensate cooled.

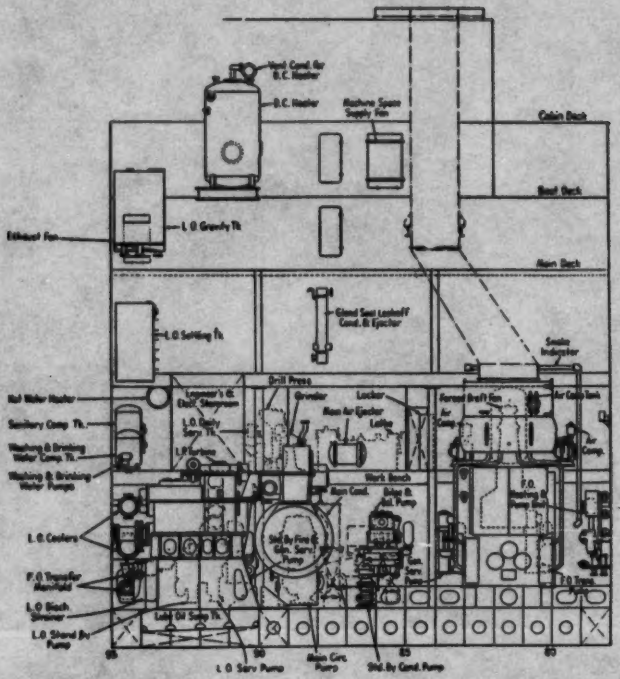
COMMISSION'S "VICTORY" SHIPS. AP-3 AND AP-2 DESIGNS.

AP-3 DESIGN—8,500 S.H.P.

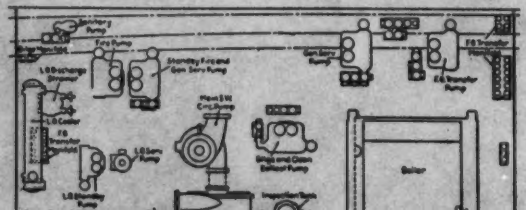
PLATE V.

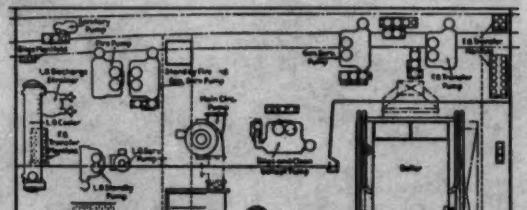
AP-2 DESIGN—6,000 S.H.P.

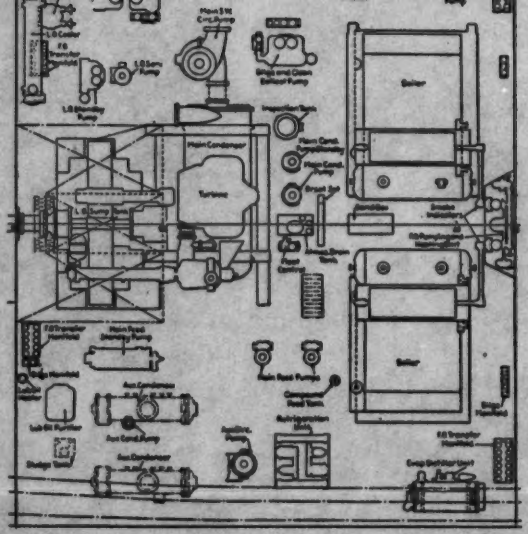


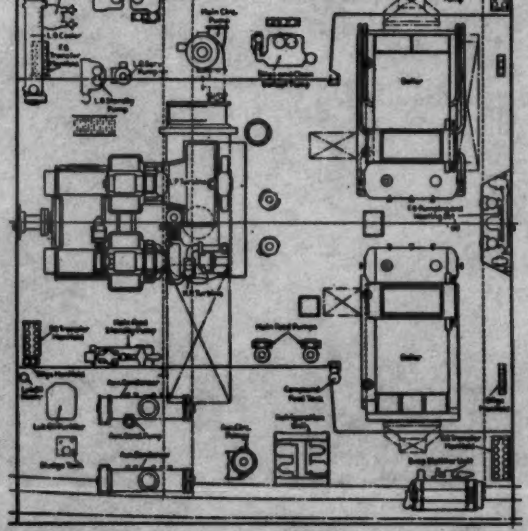


Longitudinal Sections, looking to Port.

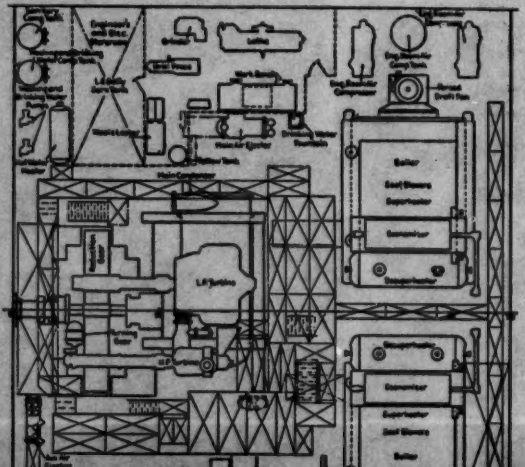


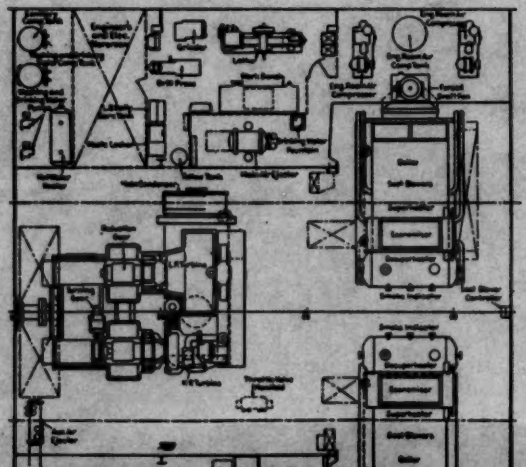


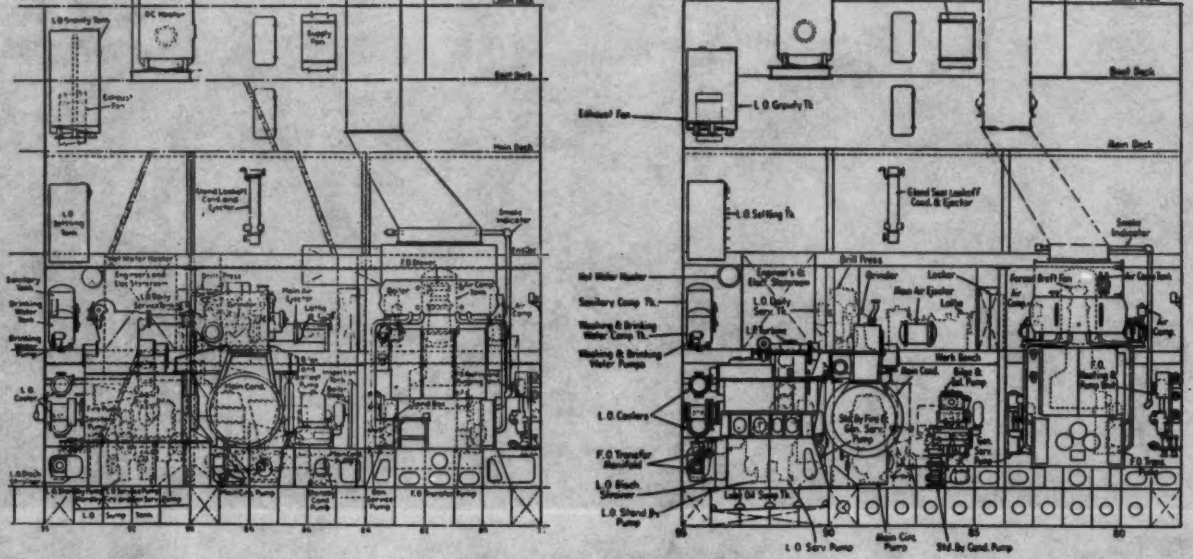




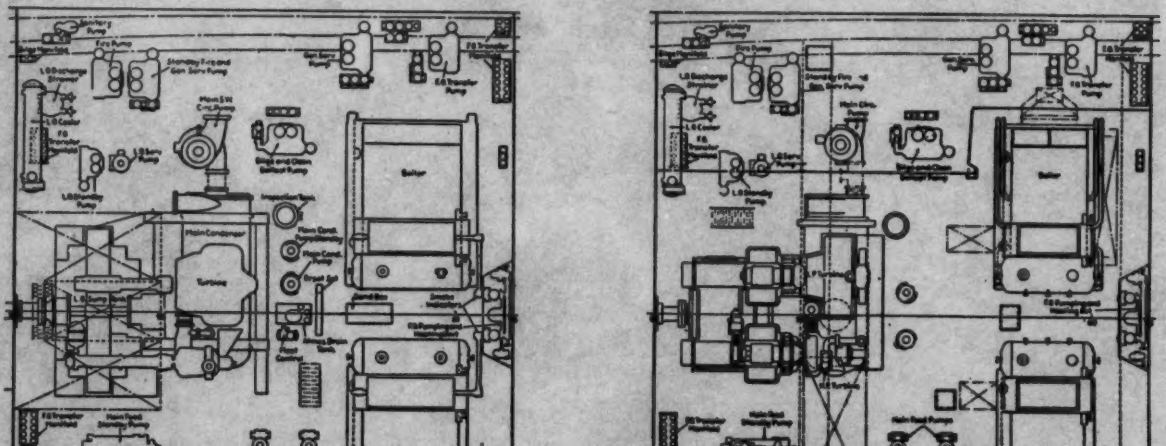
Plans of Engine-rooms at Floor Level.

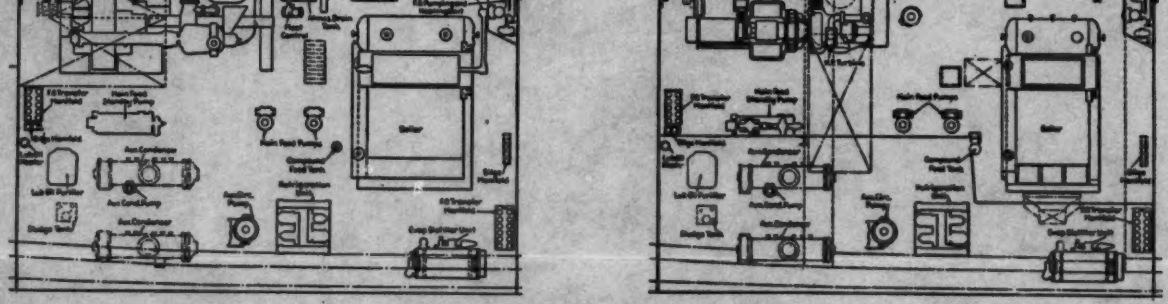




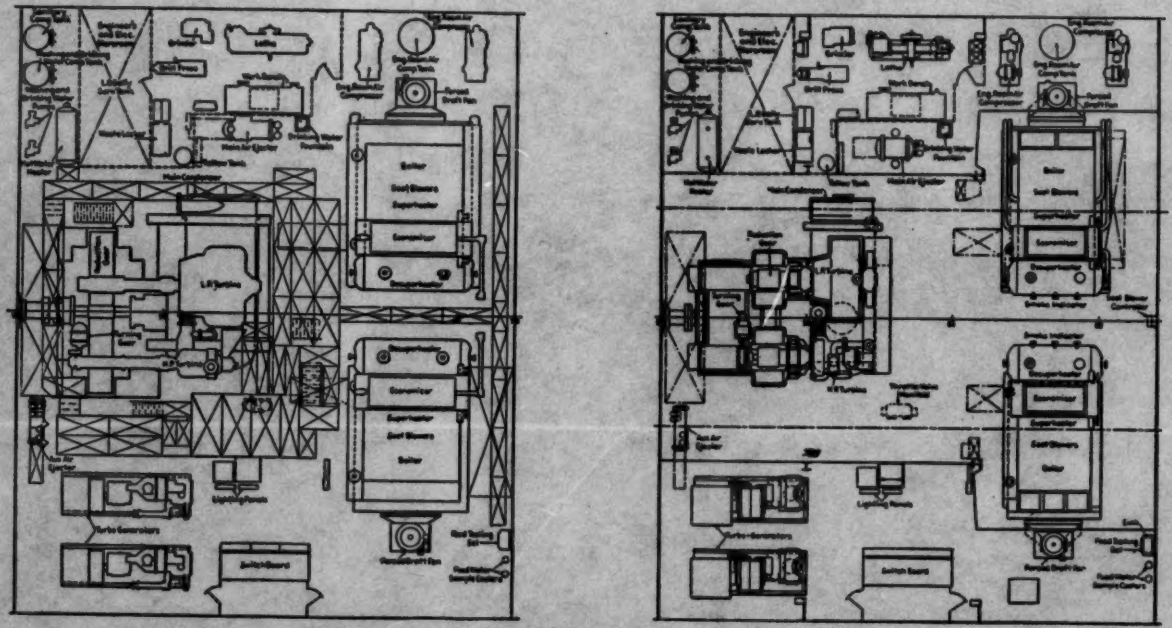


Longitudinal Sections, looking to Port.





Plans of Engine-rooms at Floor Level.



Plans of Auxiliary-machinery Platforms.

The condensers and circulating pumps in the AP-2 vessels are similar to those of the AP-3 class. The cooling surface is 6300 square feet, the circulating pump having a capacity of 10,500 gallons per minute against a total head of 10 pounds per square inch. The unit is driven at 670 Rpm. by a 75-Hp. motor.

The auxiliary condensing installation, in both the AP-2 and AP-3 types, consists of two two-pass condensers (580 square feet of cooling surface), each capable of maintaining a vacuum of 28½ inches when supplied with cooling water at 75 degrees F. For each ship there is one auxiliary air-ejector unit of the twin, two-stage type.

The gland leak-off condenser and ejector is a vertical unit, consisting of a pre-cooler, after-cooler and single-stage ejector, and is designed to maintain a vacuum of 3 inches Hg. in the pre-cooler. Steam to the ejector is taken from the auxiliary exhaust line at 10 pounds per square inch.

Air Compressors.

Compressed air for various services, including soot-blowing, is supplied by two, two-stage, single-acting compressors, each having a capacity of 60 cubic feet of free air per minute at 125 pounds per square inch and driven by a 15-Hp. motor.

Boilers.

In each vessel, two water-tube boilers of the sectional-header single-pass design are installed at the forward end of the machinery space. The drums are disposed fore-and-aft, the boilers facing each other, across a fore-and-aft firing aisle, as shown in the drawings (Plate V).

The characteristics of the boiler installations are indicated in Table III.

Table III.—Characteristics of Boiler Installations in AP-3 and AP-2 "Victory" Ships.

	AP-3 Type.	AP-2 Type.
Boiler heating surface (including furnace water walls), sq. ft.	5622	4301
Superheating surface, sq. ft.	965	729
Economizer surface, sq. ft.	1443	1031
Furnace volume, cu. ft.	605	454
Two Boilers—		
Total steam, normal, per hr.	75,000	55,000
Total steam, overload, per hr.	116,000	82,500
Superheated steam, lbs. per hr.	68,000	50,000
De-superheated steam, lbs. per hr.	7000	5000
Designed boiler pressure, lbs. per sq. in.	525	525
Operating pressure at superheater outlet, lbs. per sq. in.	465	465
Steam temperature, deg. F.	750	750
Feed-water temperature to economizer, deg. F.	240	240
Efficiency, per cent.	87.0	87.0
Air pressure, inches of water, normal	3.0	2.9
Air pressure, inches of water, overload	7.9	7.2
Heat release, B.Th.U. per cu. ft. of furnace volume, normal	82,900	81,100
Heat release, B.Th.U. per cu. ft. of furnace volume, overload	130,600	124,300
Overall Dimensions as Installed on Board—*		
Longitudinally	11 ft. 8 in.	9 ft. 4 in.
Transversely	39 ft. 6 in.	39 ft. 6 in.
Vertically (overall to top of economizer)	21 ft. 3 in.	21 ft. 3 in.
Height to center-line of drum	15 ft. 7 in.	15 ft. 7 in.

* Including firing aisle and space required for replacement of boiler generating tubes.

Though the manufacturing firms have incorporated their standard design features in the boilers for which they have been responsible, the foundations and piping connections are common to all, the work of installation being thereby greatly facilitated.

The boilers are arranged for oil firing, four oil burners being provided in each of the AP-3 and three in each of the AP-2 boilers.

The furnace side walls are water-cooled, while the front and rear walls and the floor are of refractory construction.

Inter-deck superheaters and economizers are fitted.

Air casings around the furnace extend to the top of the superheaters, the remainder of the boiler being single-cased. Air for combustion is supplied by a forced-draught fan located at the back of each boiler. The fan discharges into a rear air casing, the air passing through the side air casing and below the boiler to the burner double-front. The air casing is essential to prevent the escape of furnace gases into the fire-room, gas pressure in the furnace being positive. Moreover, the combustion air, passing around the casing, reduces radiation from the exposed surfaces and results in a cooler machinery space.

The furnace water-wall tubes are expanded into headers at the front and rear of each side wall. Opposite the tube ends in all headers, handhole plates give access for inspecting and cleaning the tubes. There are two rows of 2-inch diameter generating tubes above the furnace, the remainder of the generating tubes and the superheater tubes being 1¼ inches in diameter.

The steam drums, 42 inches in diameter, are fitted with swash-plates, baffles, etc., to ensure a dry steam supply to the superheaters.

Automatic feed-water control maintains a uniform water level, and each drum is fitted with a chemical feed connection for the satisfactory treatment of the boiler water.

Air-puff soot-blowers are installed for cleaning purposes, seven being provided in each boiler—two in the superheater, three in the boiler-tube bank and two in the economizer. For soot-blowing, compressed air at a pressure of 125 pounds per square inch is employed, the blowers being operated automatically from a controller which serves both boilers. The controller is designed to operate the soot-blowers in the correct sequence, each blowing through a prescribed arc and the only manual operations necessary being the starting and stopping of the controller. The air-type soot-blowers can be used steadily, thus enabling the tubes to be cleaned as dirt accumulates.

Air for combustion is supplied by two turbine-driven forced-draught fans of the vertical, multi-blade type, each capable of supplying the air required for one boiler up to the overload condition, the maximum capacity being 19,000 cubic feet per minute at a pressure of 10.7 inches of water. One fan serves each boiler, there being no cross-connections. The fans are driven by steam turbines of the re-entry, single-wheel type, taking steam at a pressure of 230 pounds per square inch and a temperature of 430 degrees F., the exhausts being led to the auxiliary exhaust main.

Fuel-Oil Equipment.

All equipment in the fuel-oil system between the settling tanks and the burners is contained in a "package" unit, consisting of three heaters (one standby), suction and discharge strainers, two service pumps and a meter, together with a steam-pump governor, temperature-control arrangements, air chamber, steam traps, thermometers, pressure gauges, relief valves, safety valves, piping and foundation. Each heater is designed to raise the temperature of 2600 pounds of Bunker-C fuel oil per hour from 100 to 230 degrees F. The fuel-oil pumps are of the vertical simplex type, with a capacity of 20 gallons per minute at a total head of 350 pounds per square inch. This "package" unit is supplied to the shipyard ready for installation in the engine-room.

Feed System.

The closed-feed system is arranged for single-stage heating on the unit, high-pressure principle. Condensate is withdrawn from the main and auxiliary

condensers by the main condensate pump (a vertical motor-driven, two-stage centrifugal unit), and is discharged *via* the main air ejector and gland leak-off condenser to the de-aerating heater.

The last-mentioned has a storage capacity of 1250 gallons, and is designed to heat about 80,000 pounds of feed water per hour under maximum conditions to a temperature of 240 degrees F., the oxygen content at the outlet not exceeding 0.01 cubic centimeters per liter. Steam for the de-aerating heater is taken from the auxiliary exhaust main, the supply being augmented by steam bled from the main turbines.

The two main feed pumps are vertical simplex steam-driven units(11inches by 7 inches by 24 inches), having a normal rating of 74 gallons per minute at a discharge pressure of 515 pounds per square inch and a maximum rating of 125 gallons per minute at a pressure of 600 pounds per square inch. Steam is supplied to these pumps at 440 pounds per square inch and 500 degrees F., and they exhaust to the auxiliary exhaust main. Each pump supplies one boiler only, and is fitted with a governor controlled by the water level in the boiler.

The auxiliary feed pump is a horizontal centrifugal four-stage turbine-driven unit, with a normal rating of 150 gallons per minute at 545 pounds per square inch and a maximum rating of 185 gallons per minute at 600 pounds per square inch. Steam is supplied to this unit at 440 pounds per square inch and 500 degrees F., the exhaust being led to the auxiliary exhaust main, as for the main feed pumps.

Each main feed pump is capable of meeting the requirements of one boiler at the emergency rating of 50 per cent overload. The auxiliary feed pump has a maximum capacity equivalent to maximum power.

In addition, there is one stand-by main condensate pump, duplicating the main pump but driven by a turbine. The auxiliary condensate pump, for use in port, is of the vertical two-stage centrifugal motor-driven type.

Evaporator.

There is one "package"-type evaporator-distiller unit having a capacity of 25 tons per day. It consists of a horizontal straight-tube evaporator, combined with a horizontal straight-tube distiller, fresh-water distributing pump, and a combined brine (overboard) and evaporator feed pump. This unit is designed to evaporate sea-water or raw fresh-water for boiler feed. Steam is supplied from the auxiliary exhaust main at a pressure of 10 pounds per square inch and water is distilled at atmospheric pressure. Cooling water is supplied from the main circulating system.

These units are delivered to the shipyards completely assembled with integral piping, and mounted on a foundation ready for installation.

Refrigerating Machinery.

In each ship there is one "package"-type duplex Freon-12 refrigerating unit, consisting of two vertical, single-acting, two-cylinder, motor-driven compressors, two condensers, two receivers, etc., all mounted on a common foundation. The compressors are driven by 7.5-Hp. motors, and the condensers have 35 square feet of cooling surface.

Pumps.

The installation of pumps, not previously mentioned, includes the following:—

One auxiliary circulating pump of the vertical centrifugal single-stage type; capacity 3000 gallons per minute at 10.9 pounds per square inch total head; driven by a 25-Hp. motor at 875 Rpm.

Five vertical duplex steam-driven pumps, 10 inches by 11 inches by 12 inches, one for each for the following duties:—Bilge and clean ballast; fire; stand-by; fire and general service; and fuel-oil transfer.

Two washing and drinking-water pumps of the horizontal duplex motor-driven type; capacity 10 gallons per minute against a discharge pressure of 60 pounds per square inch.

One sanitary pump of the horizontal centrifugal motor-driven type; capacity 60 gallons per minute against a total pressure of 85 pounds per square inch.

Electrical Plant.

Electric current is supplied by two 300-Kw., 240/120-volt, three-wire generators, each driven by a steam turbine through reduction gearing. The turbines operate with steam at 440 pounds per square inch pressur e d 740 degrees F., and each exhausts to its own condenser (vacuum 28½ inches Hg.). The generators of the AP-3 vessels are compound-wound, those of the AP-2 vessels being either shunt or compound-wound, the former predominating. Neither type depends on voltage regulators, the compound machines having equalizing connections, while the characteristics of the shunt machines are such that successful parallel operation is expected without this feature. The capacity of the generating plant is such that one unit will normally carry the load at sea.

The main switchboard is of the dead-front type, comprising four panels for the control and operation of the main generators and the protection of the power and lighting feeders. From the main switchboard, current is distributed to a number of lighting and power panels of the tumbler-switch type and to certain individual auxiliaries. The loads on the feeders are divided functionally; for example, a ventilation feeder serves only a group of fans, and it is possible to interrupt all ventilation in case of fire from a push-button in the wheelhouse.

The Diesel-driven 15-Kw., 120/240-volt, emergency generator is a three-wire compound-wound unit. The emergency switchboard, of the dead-front type, is located in the same compartment, and is normally fed through an interconnecting bus feeder from the main switchboard. On loss of voltage from the main plant, the emergency load is automatically transferred to the emergency generator.

SUB-ZERO TREATMENT OF STEEL.

In this article reprinted from the October, 1944 issue of Machinery, H. C. Amtsberg reports a new departure in shop practice. Recent investigations into the changes that take place in steel when subjected to very low temperatures following the usual heat treatment open up an entirely new field in the treatment of cutting tools and tool steels in general. Mr. Amtsberg is a Metallurgical engineer in the employ of Westinghouse Electric and Manufacturing Company.

Large numbers of reports and several articles have been written on the improved properties and performance brought about by sub-zero cooling of steel parts, particularly tools. Claims of several hundred per cent improvement in life of tools, while probably exaggerated, are not uncommon. The treatment has also been a partial cure for improper initial heat-treatment. In either case, the value of the process is unquestioned. It is likely to become a routine part of normal heat-treating practices, and sufficient authoritative information is already available to warrant a sustained program of actual exploitation in the shop and further study in the laboratory. Therefore, a presentation of the fundamentals of cooling hardened steels to temperatures considerably below room temperature, properly correlated with the basic treatment cycle and related structural changes, should be of considerable interest.

When steel is heated to its hardening temperature, the structure consists of a solid solution of carbon in iron, known as austenite, with or without alloying elements in solution, and with or without free iron or alloy carbides, depending on the composition and temperature. Austenite is relatively soft, tough, and ductile, even at room temperature. The carbides are very hard compounds of carbon and iron or alloying elements such as chromium, tungsten, molybdenum, and vanadium. In hardening such steel by cooling in some

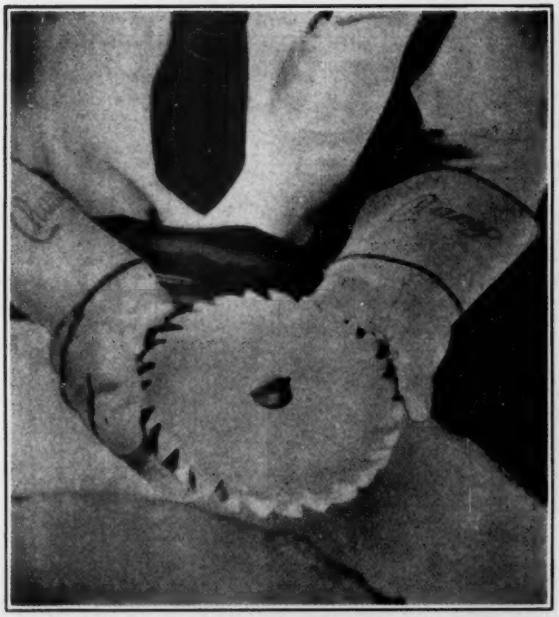


FIGURE 1.—MILLING CUTTER OF HIGH-SPEED STEEL BEING REMOVED FROM SUB-ZERO CHAMBER.

This cutter was first oil-quenched from 2350 degrees F. Then tempered at 1050 degrees F. for two and one-half hours, and then cooled to minus 100 degrees F. in the sub-zero chamber. The milling cutter will be ready for use following another tempering of one hour at 1050 degrees F.

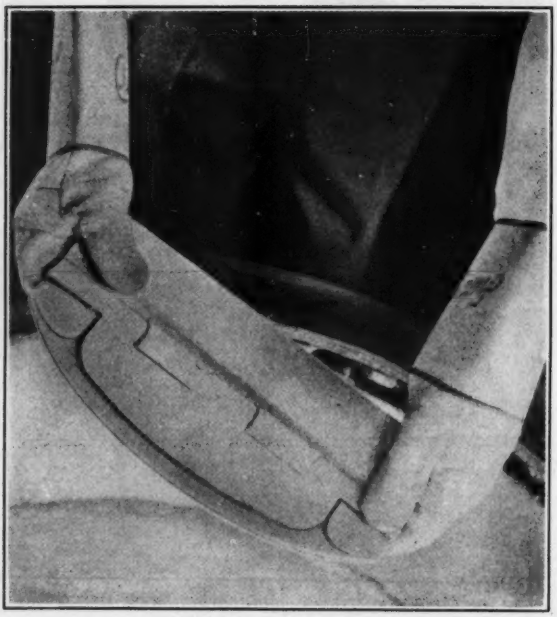


FIGURE 2.—HUBBING MASTER OF HIGH-CARBON HIGH-CHROMIUM TOOL STEEL FOR SINKING PLASTIC MOLD DIE CAVITIES.

It is first hardened in the conventional manner to 65 Rockwell C.; then tempered in boiling water for one hour; cooled to minus 100 degrees F. in a sub-zero chamber; warmed to room temperature; and tempered at about 900 degrees F. to a hardness of 60 to 62 Rockwell C.

suitable medium, the austenite transforms to martensite—a hard and strong constituent that is an aggregate of finely dispersed carbides in iron. This aggregate bears some similarity to suspensions such as colloidal graphite in water, except that the particle size in the former is much finer.

As explained in greater detail later, an ideal hardening operation would be one in which all of the austenite was transformed to martensite upon reaching room temperature. This is true even if the final hardness desired is much lower than would result from this ideal hardening, for it is well known that the best physical properties are obtained by quenching (in water, oil, or air) to maximum hardness, and then tempering to the desired combination of hardness and strength relative to ductility and toughness.

Why Steels Do Not Always Attain Maximum Hardness.

In many steels, however, the transformation of the soft high-temperature constituent austenite to the hard constituent martensite is not always complete. In other words, after the steel has been cooled to room temperature, some austenite is still retained. This is illustrated in Figures 3 and 4, which show isothermal time-temperature transformation curves of a high-speed steel determined by Gordon, Cohen, and Rose (1),* and an air-hardening die steel by Payson and Klein (2), respectively, on which cooling curves for standard treatments have been superimposed.†

In Figure 3, it will be seen that oil quenching of 18-4-1 high-speed steel to room temperature transforms only about 75 per cent of the structure to martensite, while 25 per cent remains as untransformed austenite. Figure 4 shows that about 5 per cent of austenite remains in the chromium air-hardening steel after cooling in air to room temperature.

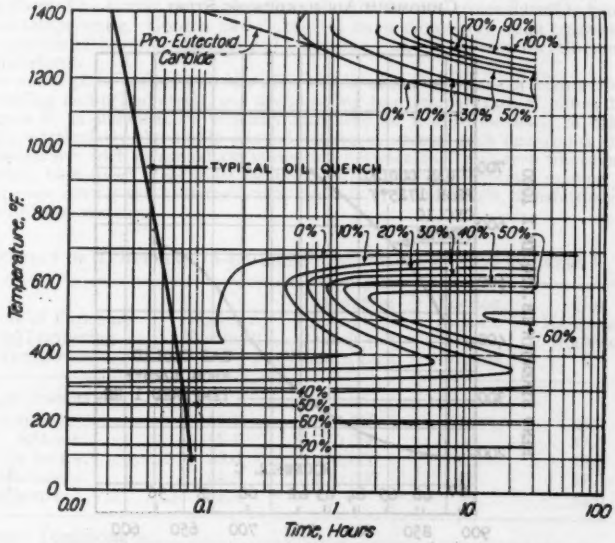


FIGURE 3. TIME-TEMPERATURE TRANSFORMATION CURVE FOR 18–4–1 HIGH-SPEED STEEL.

* The figures in parentheses refer to the bibliography at the end of this article.

† For a fundamental discussion on isothermal transformation curves, the reader is referred to studies of the subject by Davenport (3) and Greninger and Troiano (4).

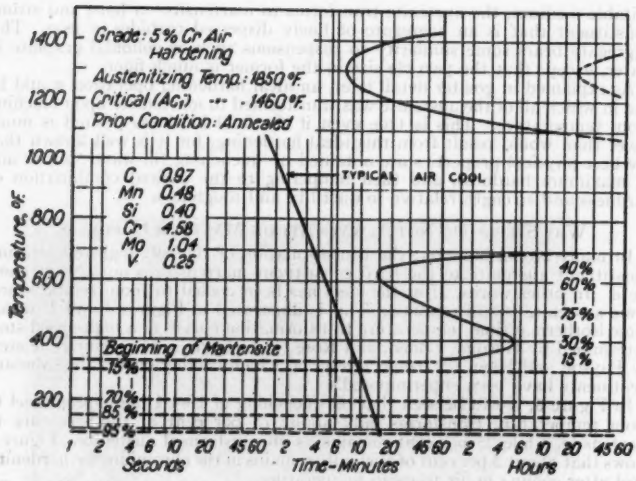


FIGURE 4. TIME-TEMPERATURE TRANSFORMATION CURVE FOR 5 PER CENT CHROMIUM AIR-HARDENING STEEL.

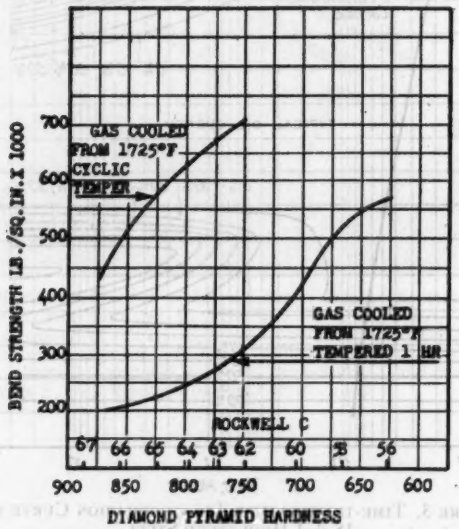


FIGURE 5. EFFECT OF CYCLIC TREATMENT ON THE BEND STRENGTH OF AIR-HARDENING STEEL CONTAINING 1 PER CENT CARBON, 5 PER CENT CHROMIUM, AND 1 PER CENT MOLYBDENUM.

Many other steels retain austenite in a similar manner, provided the cooling is sufficiently rapid to prevent transformation at a high temperature to a relatively soft product—pearlite. The cooling rates of the steels in Figures 3 and 4 could be reversed and the amount of austenite retained in each case would be about the same. K. Honda and K. Iwase (5) have shown that more austenite *may* be retained by oil quenching than by water quenching, probably due to the greater thermal stress produced by the latter. It is believed that the same phenomenon exists in higher alloy steels when air or oil quenched.

It is impossible to give a specific rule, but it may be generally said that the higher the carbon and alloy content and the higher the hardening temperature, the greater will be the tendency to retain austenite. Thus, it is apparent that mixed structures of this nature may be present frequently in "as quenched" steel.

Transforming the Retained Austenite.

The transformation of retained austenite can be effected in a number of ways. In a few steels, in which the amounts of retained austenite are relatively small, a sufficient length of time (sometimes months or years) at room temperature will change all or nearly all of it to martensite. This, of course, is frequently disadvantageous, particularly in the case of dies and gages, because full hardness and dimensional stability are not obtained at once. This explains the inability of many gages to maintain their shape and size accurately over a long period of time. In all steels, the austenite can be transformed by tempering; but, frequently, such high temperatures are required as to lose the hardness of the martensite and cause transformation of the austenite to a softer product—bainite.

Referring again to Figures 3 and 4, it is obvious that the austenite can be transformed by simply continuing the cooling of the steel to considerably below room temperature. Gordon and Cohen (6) have shown how such treatment reduces the stability of the retained austenite—that is, reduces its reluctance to transform.

In many plain carbon and low-alloy steels, either medium- or high-carbon (including carburized steel), one such cooling to a temperature of minus 100 degrees F. is sufficient to virtually complete all transformation. In other steels, particularly the highly alloyed die steels, several such operations may be necessary, with intermediate tempering between each sub-zero treatment. In fact, high-speed steel must be tempered in the conventional manner at least once during the heat-treatment cycle in order to obtain transformation of all of the austenite.

Effect of Tempering 18-4-1 High-Speed Steel at 1050 Degrees F.

Time of Exposure to Tempering Temperature.	Hardness, Rockwell C	Transverse Strength, Pounds per Square Inch.	Torsion Impact, Foot-Pounds	Hot Hardness,* Rockwell C
Single Tempering—				
6 minutes	65.1	312,000	16	55.0
½ hour	65.7	270,000	30	57.0
2½ hours	65.0	408,000	48	58.0
5 hours	64.5	410,000	48	57.0
24 hours	63.8	—	39	55.0
Double Tempering—				
2½ hours plus 2½ hours	64.5	454,000	63	57.0

* Hot Hardness measured at 1000 degrees F.

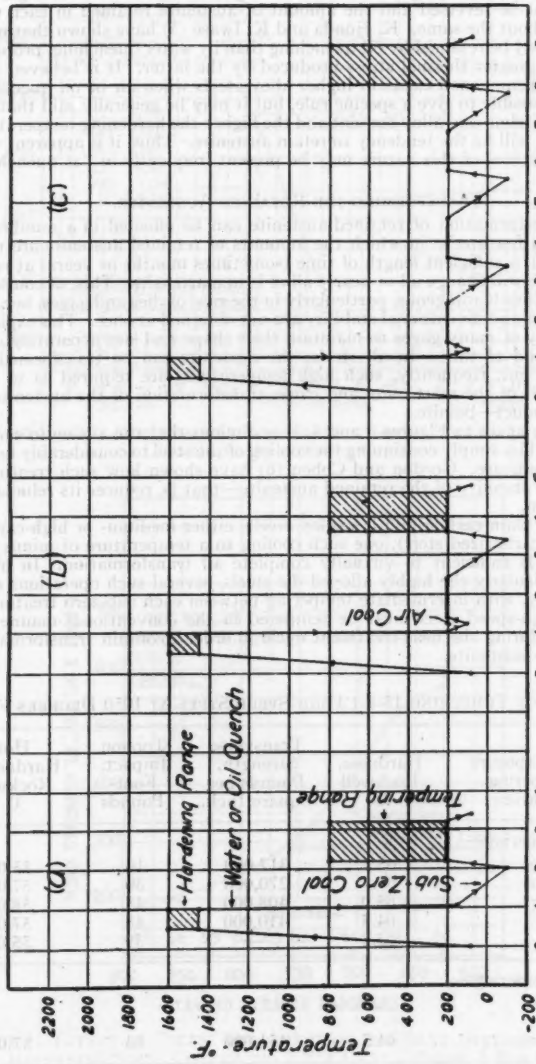


FIGURE 6. CYCLES IN THE HEAT-TREATMENT AND SUB-ZERO TREATMENT OF WATER- AND OIL-HARDENING TOOL STEELS AND ALLOY CARBURIZING STEELS.

Value of Sub-Zero Treatment of Steel.

Now that it has been determined how an austenite-free structure can be obtained, the question may be asked, Is it worth while to go to all this trouble? It is well known that, from the mechanical property standpoint, the amounts of retained austenite and untempered martensite should be at an absolute minimum in the final product. Repeated tests by Cohen and his coworkers (6, 7) have indicated higher strength and toughness without appreciable loss in hardness when all the austenite has been transformed by tempering or sub-zero treatment, especially the latter, and this is particularly true when the completely transformed structure is given a final temper for stress relief.

H. Scott and T. H. Gray, metallurgical section engineer and consulting metallurgist, respectively, Westinghouse Research Laboratories, have shown (see Figure 5) a more than 200 per cent increase in transverse bend strength over a considerable range in hardness by a cyclic treatment after hardening. This consisted of alternately tempering in boiling water and cooling to minus 100 degrees F. three times, followed by a final temper to the desired hardness. Evidence has been offered in the case of high-speed steel showing that all of the austenite can be transformed by tempering one or more times at the usual temperature (1050 degrees F.) followed by cooling to room temperature after each heating. The amount of austenite that will be transformed is dependent on the length of time the steel is exposed to the tempering temperature; the effect of the progressively reduced amounts of austenite on the properties of the steel is shown in the accompanying table [Cohen (8)].

The effect of these improved properties has been substantiated by actual shop results, where reduced breakage and edge chipping, longer cutting life, and more blanks per grind have all been obtained.

As previously pointed out, it is usually desirable to have the transformation take place at relatively low temperatures (under 300 degrees F.). This necessitates a note of caution, since steels containing considerable proportions of austenite are provided with a "cushion" of high plasticity for the accommodation of considerable stress. If this "cushion" is removed, particularly at very low temperatures where plasticity in general is quite low, stresses resulting from natural dimensional changes will occur, which connotes a serious cracking hazard. With these facts in mind then, an approach to the practical application of sub-zero treatments can be made.

Application to Different Types of Steel.

For carbon or moderately alloyed steels of medium carbon content, such as SAE 1045, 4140, 4340, and NE equivalents, the practical value of sub-zero cooling is questionable, because the amounts of retained austenite are either nil or relatively small. Furthermore, in most engineering applications of steels of this type, the tempering temperatures are fairly high and the hardness considerably reduced, so that the conversion of the austenite to bainite would not be objectionable. Bainite, untempered or tempered, is known to have excellent properties for applications that do not require maximum hardness.

For water- and oil-hardening tool steels, alloy carburizing steels, and other low-alloy high-carbon steels such as SAE 52100, the treatment has been found frequently beneficial. Typical cycles are illustrated in Figure 6. In general, cycle (a) is satisfactory for virtually all alloy carburizing steels and, in some cases, for other steels as well. Cycles (b) and (c) offer considerably reduced danger of cracking, particularly in cases where there are sharp corners or edges or where the part has hardened throughout the cross-section. Cycle (c) is especially advantageous for gages, since it offers the grestest degree of stabilization. In all cases, the final temper is the last operation, and this is true of all subsequent treatments discussed.

The curves indicate actual steel temperature. While the time relationships are not intended to be exact (except where specifically stated), it is significant to note that it is not deemed necessary to hold the steel at the sub-zero temperature for any appreciable length of time; but it is important that the steel reach the temperature given.

High-Alloy Die Steels.

Treatments for the highly alloyed die steels, as shown in Figure 7, are very similar, except that two, and sometimes more, immersions in the sub-zero cooling medium are necessary to obtain optimum properties, since the austenite is considerably more sluggish—that is, resistant to transformation. Somewhat inferior properties probably result from cycle (b), as against cycle (a), due to "aging" (subsequently explained in the discussion on high-speed steel). Cycle (b) does, however, offer greater freedom from the cracking hazard.

Since steels that have been sub-zero treated have considerably greater strength at a given hardness, tools made from them can be used at higher hardness than those subjected to ordinary heat-treating practice. By the same token, if breakage in service had been a serious problem previously, tempering to the same hardness as used with conventional treatment would produce much greater toughness.

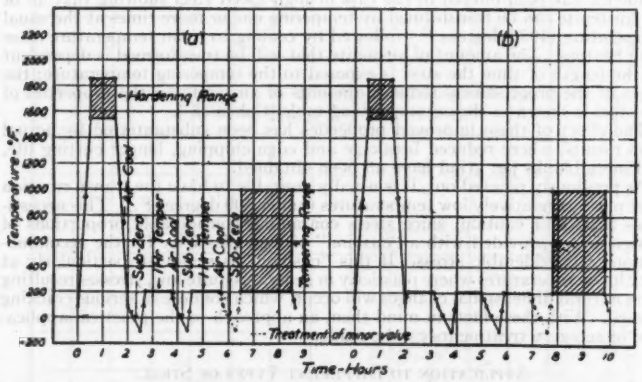


FIGURE 7. CYCLES FOR THE TREATMENT OF CHROMIUM-MOLYBDENUM, MANGANESE-CHROMIUM-MOLYBDENUM, AND HIGH-CARBON HIGH-CHROMIUM AIR-HARDENING TOOL STEELS.

Application to High-Speed Steel Tools.

Figure 8 illustrates several cycles for the treatment of high-speed steel. The regular salt bath technique can also be employed, the only difference being that the steel is air-cooled following the customary quench in a salt bath held at a temperature of approximately 1100 degrees F. High-speed steel, however, because of some anomalous behaviors, requires additional explanation. Cycles (a) and (b) are of equal effectiveness, and would seem most likely to produce the best results in performance of all the heat-treatments given. It should be pointed out, however, that this is not definitely established. Berlien (9) and DePoy (10) have obtained opposing results in independently conducted service tests. Cohen (8) reported, however, that beneficial results have been obtained by sub-zero treating of *finished* tools, which seems to indicate an effect or factor that has not yet been explained.

It will be noted that, even when the cooling is more or less continuous from the quench to the sub-zero temperature, double tempering is recommended. Cohen (6, 8) has shown this to be because the first cooling still leaves approximately 9 per cent of the austenite untransformed, and no amount of time or a lower temperature will appreciably alter this condition. According to Cohen and Koh (11), it is, therefore, necessary to "condition" the remaining austenite

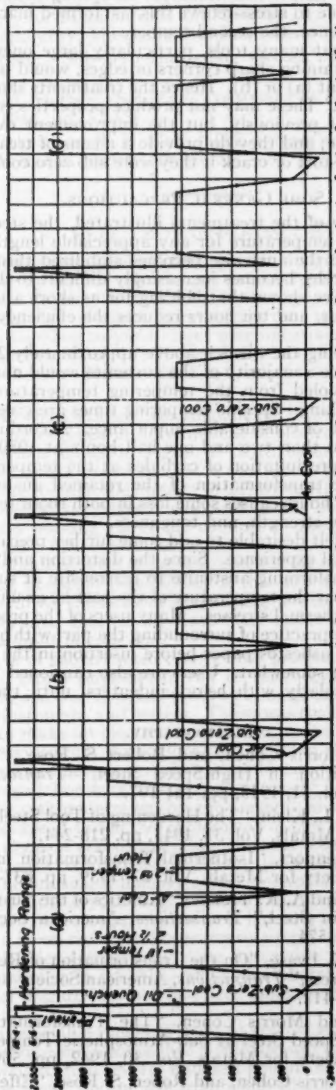


FIGURE 8. CYCLES IN THE HEAT-TREATMENT AND SUB-ZERO TREATMENT OF HIGH-SPEED STEELS.

by the first temper, so that it will transform on cooling to room temperature. Of course, it is desirable to stress-relieve this last formed martensite to obtain the best properties; hence, the second temper.

It is appreciated that many tools, particularly large ones of complicated section and those containing sharp corners or edges, would be prone to crack if given either treatment (a) or (b). Hence the treatments shown by cycles (c) and (d) are suggested. These may not produce properties equal to cycle (a) or (b), as pointed out previously, but the improvement over conventional practice is considerable; and they do provide a means of treating shapes that would be certain to distort or crack if they were sub-zero cooled directly.

Some General Precautions.

In carrying out any of the treatments illustrated, the steel should not be held at or near room temperature for any appreciable length of time before sub-zero cooling, since the austenite becomes stabilized through an "aging" phenomenon, and thereby becomes increasingly difficult to decompose. Gordon and Cohen (6) have shown that holding for as short a time as one hour has a detrimental effect, and ten hours reduces the efficiency of the sub-zero treatment 50 per cent.

Furthermore, arresting the quench above approximately 225 degrees F. is not recommended, since a majority of the austenite would not be transformed until the steel was cooled from the tempering temperature, with an even greater hazard of cracking. Specific tempering times are given for high-speed steel, because they are of considerable importance. According to Cohen (8), the first temper, if less than two and one-half hours at 1050 degrees F., will not permit sufficient precipitation of carbides at the tempering temperature to allow for complete transformation of the retained austenite on cooling, while more than three hours causes some loss in both room temperature hardness and hot hardness, strength, and toughness.

In conclusion, it is felt desirable to add some further precautions that have been dictated by actual experience. Since the distortion and cracking hazard is ever present in transforming austenite to martensite at such low temperatures, it is desirable that the temperature of the part be as uniform as possible to prevent additional thermal stresses. Many users of the process have, consequently, employed the practice of surrounding the part with one or more layers of heavy wrapping or asbestos paper before insertion in the cooling medium to slow up the cooling somewhat. Users are also cautioned to avoid making hardness tests, particularly with heavy indenters, until the part has been tempered.

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ELECTRON MICROSCOPY.

Electron microscopes theoretically permit magnifications 10,000 times those obtainable by optical microscopes yet, as Igor B. Bensen points out in his article, their development is still in the age of infancy. Allegorically speaking, present-day electron microscopes are merely crude magnifying glasses stacked together to yield larger magnifications. Mr. Bensen is in the Electronics Laboratory of the General Electric Company. His paper is reprinted from General Electric Review, December, 1944.

Up until 1940 the German firm Allgemeine Electricitäts Gesellschaft was the only company engaged in development of electrostatic microscopes. One of its late models is shown in Figure 1. Until even later, most microscopes were strictly physicists' creations: space was used freely (power supplies often occupied separate rooms), the number of adjustments and controls was usually as great as possible, no respect was paid to the convenience and speed of operation, to say nothing about the comfort of the operator, while cost and economy were only minor considerations.

The results obtained with these instruments, however, proved beyond any doubt the great potential possibilities of this new scientific tool. It became evident that with its tremendous magnifying power, the electron microscope would sooner or later find its way into most scientific laboratories, following the path of the light microscope.

But, the state of the art wasn't as yet too promising: not every laboratory could afford to hire a physicist to run its microscope; and to a layman the electron microscope was hopelessly beyond comprehension, with its innumerable knobs, adjustments, and meters. There was room, therefore, for advanced development to make an electron microscope basically simple, not too costly to build, and easy to run. Fundamentally, nothing was so intricate about the use of electrons in microscopes that it could not be simplified to the point where an average laboratory assistant could easily handle the instrument.

This was the task undertaken by the General Electric Electronics Laboratory. In the course of this active exploration of new and more radical arrangements for the electron microscope, three new versions of the electrostatic type of instrument were studied because they presented good opportunities to demonstrate the unusual simplicity of the electrostatic principle.

As a result of a three-year effort the Laboratory has produced the first truly portable electron microscope ever built. It has only two electrical controls (like two knobs on a home radio) and operates as simply as a good light microscope. It climaxes the development of three successive units: The conventional vertical style (similar to the AEG unit), the laboratory model (Figure 2), and the War Model (Figure 3) which had been announced to the public in November, 1942.

Work on the portable model (Figure 4) started early in 1943. The task of building an electron microscope into a suitcase was not an easy one. It meant reduction of weight from several hundred pounds to something not too heavy to carry in one hand; and of size from some 40 cubic feet of bulk volume to 3 cubic feet or less. With the electrostatic principle of electron optics, however,

it did not seem inconceivable, especially in view of the previous experience with the War Model, which in itself was a great step toward simplification.

Before undertaking a description of these simplified microscopes it seems worth while to review briefly the theory of the electrostatic electron optics employed in them.

It was E. Abbé, a famous optician, who first correlated the limit of resolution of an optical instrument to the wavelength of the radiation it used. According to his formula, maximum resolution is given by:

$$R = K\lambda/NA$$

where R = smallest distance between two resolvable points
K = constant of illumination, usually 0.5
λ = wavelength of light used
NA = numerical aperture of the lens (1.4 for oil immersion)

This means that the maximum resolving power is in direct proportion to the wavelength; thus, for an ordinary microscope employing light of, say 5000 Ångstroms (Å = 10^{-10} meters or 10^{-4} microns), the theoretical limit o resolution would be, roughly, 2000 Å. Converting this into useful magnification (a human eye's resolution is 0.1–0.2 millimeters), the light microscope is capable, therefore, of magnifying $0.2 \div 2000 \times 10^{-7}$ or $1000 \times$ without appreciable distortion. Beyond this limit no additional information is gained because of diffraction effects and general blurring. Thus, E. Abbé became convinced that the wavelength of light would forever keep the human eye from penetrating into the secrets of the submicroscopic world.

This pessimism was not dispersed until the development of the "ultra microscope," employing invisible ultraviolet radiation in the range of 2500 Å, which extended useful magnifications up to $2000 \times$, because of the shorter wavelength used.

However, a real word of hope for greater magnifications came with the discovery of the wave nature of electrons in motion. In 1924 de Broglie formulated the relationship between the wavelength of an electron and its velocity. According to his expression:

$$\lambda = K/\sqrt{E}$$

where λ = wavelength
K = de Broglie constant
E = accelerating potential

The wavelength of an electron is inversely proportional to the square root of the potential applied to accelerate it.* A brief inspection of this formula will reveal tremendous possibilities for electrons if they only could be made to magnify the images. Indeed, the wavelength of electrons, attainable well within practical limits, may be as short as 0.5 Å, which is 10,000 less than that of light. Therefore, theoretically the electrons should permit magnifications 10,000 times greater than those obtainable with light.

The theory of de Broglie was verified by subsequent experiments, and there remained only to devise an electron lens. Such a lens was soon announced by Bush, in 1926. Bush has proved that in his lens:

(1). All electrons departing in different directions from one point will converge again at one point.

(2). This is true not only for points along the optical axis, but, with sufficient approximation, for all points near the axis.

(3). Most aberrations and characteristics of such a lens are very analogous to those encountered in glass optics.

* It is convenient here to give electron velocity in terms of volts applied to propel them rather than in terms of feet per second since the latter has little practical significance.

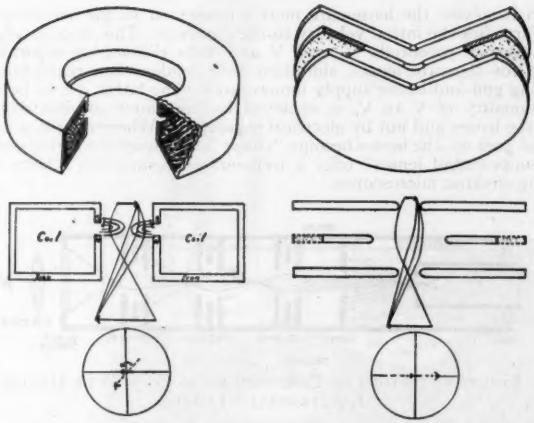

FIGURE 5. ELECTRON LENSES: LEFT, ELECTROMAGNETIC; RIGHT, ELECTROSTATIC.

Either an electrostatic or an electromagnetic field possessing axial symmetry acts as an electron lens, provided electrons travel nearly along its axis (Figures 5 and 6). The axis of symmetry of the lens is also called the optical axis. The focal length of an electromagnetic lens is then given by the following equation:

$$\frac{1}{f} = \frac{K}{V_0} \int H_z^2 \, dz$$

where f = focal length in cm
K = constant
V_0 = electron velocity in volts
H_z = magnetic field intensity along E axis, in oersteds

while for an electrostatic lens

$$\frac{1}{f} = -\frac{K}{\sqrt{V_0/V}}$$

where V = lens potential

In each instance the focal lengths are determined by lens constants and two independent parameters. In regard to an electrostatic lens, however, it can be seen at a glance that since both parameters are under the same radical there is some chance for further simplification. In fact, if the lens potential V could be made proportional to the electron-velocity potential V_0, the radical V_0/V would become constant and such a lens would have constant focal length!

This has been done in the electron microscopes developed by the Electronics Laboratory.

The problem of holding focal lengths constant is of primary concern in electron microscopy if a steady, well-focused image is to be obtained. This problem is nonexistent in light optics because of the permanent nature of glass lenses—once they are ground, their focal lengths are fixed by their geometry. In electron optics, however, close regulation of power supplies, with its often cumbersome and expensive equipments, is necessary. The device employed in our electrostatic lenses is surprisingly simple compared to the size of the

problem it solves: the lenses are merely connected to the accelerating gun, which furnishes the initial velocity to the electrons. This step, in addition to tying together potentials V_0 and V and thus eliminating separate power supplies for separate lenses, simultaneously renders fine regulation of the remaining gun-and-lenses supply unnecessary. The latter is true because the proportionality of V to V_0 is achieved by constancy of field distribution within the lenses and not by electrical regulation. Whenever the accelerating potential goes up, the lenses become "stiffer" and the effects cancel out. Thus, such "unipotential lenses" offer a tremendously simplified scheme for constructing electron microscopes.

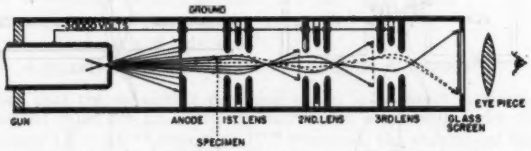

FIGURE 6. LAYOUT OF ELECTRON-MICROSCOPE TUBE HAVING ELECTROSTATIC LENSES.

Figure 6 shows diagrammatically a complete layout of a microscope with three lenses. These lenses are directly connected to the gun.

ELECTROSTATIC LENS ACTION.

The disk-type lens chosen for the new microscopes is just one of many forms of electrostatic lenses known to electron microscopists. It is easily machinable and lends itself to accurate prealignment; these were the main features that decided its being chosen for the simplified instrument. Figure 5 (*right*) shows a sectioned view of such a lens.

Mathematical approximations were worked out to describe the path of electrons inside this lens, but even without this aid the mechanism can be visualized clearly by considering once again the fundamentals. It must be remembered that an electron is a negatively charged particle. It is attracted by positively charged surfaces and repelled by negatively charged ones. This property was utilized in the gun to speed up the electrons by means of the anode which was charged to 30,000 volts. Electrons travelling at this speed arrive at the outer plate of the lens. Since this plate also runs at 30,000 volts positive, it exerts no force on the electrons, allowing them to pass freely through its aperture. As soon as they enter the space inside the lens, however, the field gradually becomes negative because of the presence of the negatively charged central plate (Figure 6). The electrons feel this change in the form of a repulsive force pushing them away from the periphery or, in other words, toward the optical axis because of the hole in the central plate. The originally divergent beam then is slowly forced to decrease in diameter and, if the central aperture is small enough, subsequently to become convergent. This is exactly the action of a positive lens. By the time the beam reaches the third plate, its diameter is small enough again to pass freely through the small aperture of that plate. Upon emerging from the lens, the electrons enter the gradient-free space and travel rectilinearly, in the form of a divergent cone, until they reach another lens. The process is then repeated.

ELECTROSTATIC LENS.

Proportionality of the lens potential to the electron-velocity potential is maintained at the center of the lens simply because of the constancy of field distribution within the lens. The center electrode, which runs at gun potential, has a sufficiently large opening in the middle to reduce the effective lens potential V to a fraction of V_0, this fraction being dependent only upon the geometry of the lens. A real contribution to the art is in placement of the high-voltage

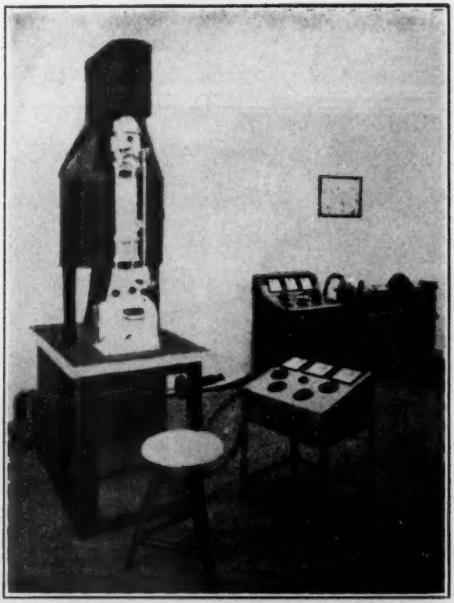

FIGURE 1.—AEG ELECTROSTATIC ELECTRON MICROSCOPE.

FIGURE 2.—LABORATORY MODEL.

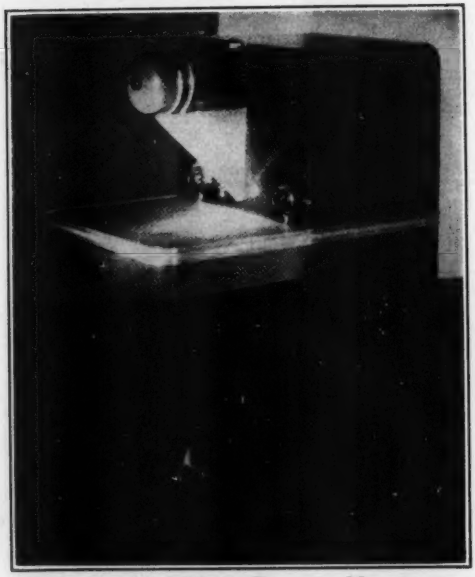

FIGURE 3.—WAR MODEL ELECTRON MICROSCOPE.

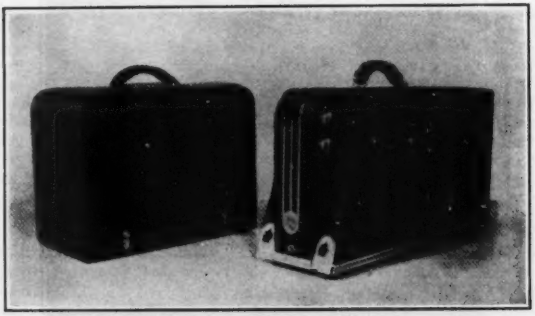

FIGURE 4.—PORTABLE MODEL.

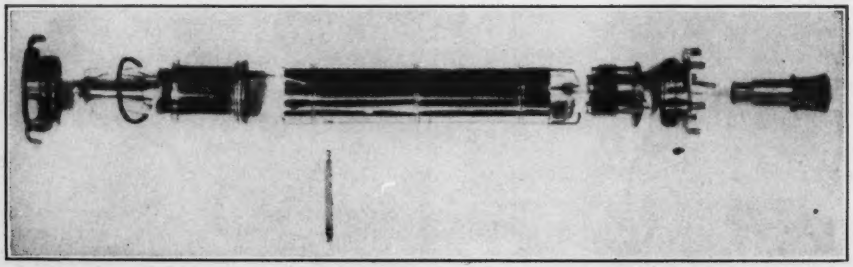

FIGURE 7.—OPTICAL COMPONENTS OF ELECTROSTATIC MICROSCOPE.
Notice also rubber gaskets and clamping rings for vacuum-tight seals on ends. Vacuum chamber is not shown.

FIGURE 10.—CAMERA MOUNTED ON THE PORTABLE UNIT.

FIGURE 12.—CARBON STEEL (PEARLITE STRUCTURE) AT 10,000 X MAGNIFICATION.

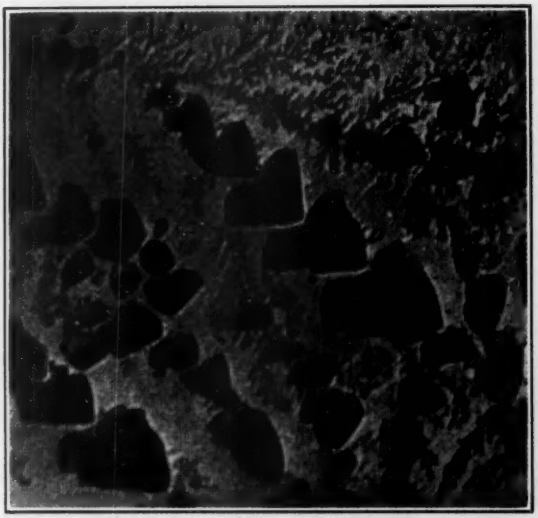

FIGURE 13.—TABLE SALT (SODIUM CHLORIDE CRYSTALS) AT 10,000 X MAGNIFICATION.

lead inside of the vacuum. Earlier electrostatic microscopes connected the lenses with the high-voltage supply by means of external conductors (Figure 1). They were dangerous and quite bulky. Interconnecting the lenses and the gun inside the vacuum permitted great reduction in the over-all size of the microscope, in addition to making it even safer than a cathode-ray tube. Naturally, the high-voltage lead is well shielded from the electron beam; otherwise it would deflect the beam away from its axis (Figure 8).

Mechanism of Image Formation.

Referring to Figure 6, it is not difficult to follow the path of electrons from their origin to the final image. At the extreme left end, power is fed into the "electron gun." This gun consists of a V-shaped tungsten filament with a small aperture just in front of its tip. In operation this filament is electrically heated to incandescence. A short distance farther in front is the anode of the gun, running at a very high positive potential (30,000 volts is common in our instruments). The anode produces a strong electrostatic field which draws the electrons with great force from the filament tip toward the anode. The anode itself, however, has an opening in its center, thus allowing some of the electrons to progress farther into the vacuum chamber.

Having gained the full velocity of 30 Kv., the electrons pass through apertures in two soft iron disks, then the beam-defining aperture, and finally strike the specimen. The iron disks are placed there to protect the subsequent stages from stray magnetic fields.* The function of the beam-defining aperture is to limit the width and the angle of the beam to an optimum size at which the resolution of the instrument is the best. Experimentally it was found that best resolution was obtained with a 0.004-inch hole, without detriment to the brightness of the final image. It corresponds to a solid angle of illumination of approximately 10^{-5} radians. This value, incidentally, checked the theory developed by von Borries in 1939.

The sample is mounted on a micromanipulator with which it can be moved in three mutually perpendicular directions: one axial motion for focusing and two stage motions for scanning the field of the sample. Samples must be semitransparent to the electrons in order to produce a good transmission image. If samples are nontransparent, shadow pictures are obtained, which may still furnish desired information to the operator. Studies of particles, for example, are done almost exclusively with shadow pictures.

Lenses.

After the beam passes through the specimen, it carries the valuable "intelligence" which must be carefully transmitted to the observer, without distortions and in good contrast. Then it measures only 0.006 inch in diameter, but even from this much only a hundredth of its original area is used to produce the final image at 1000 diameters. The remainder is discarded as not sufficiently close to the optical axis. Thus, only about three ten-millionths of a square inch of the specimen is exposed at one time to the observer. Obviously, then, a stage motion is provided to cover reasonably large fields on the sample.

Having acquired the information of the specimen, the beam finally enters the lens system. At 1000 × magnification each of the three lenses magnifies 10 ×, while the second and third lenses also act as beam limiters. Peripheral portions of the beam which do not contribute to the final image on the screen are rejected by front apertures of each of these lenses. This is clearly shown in Figure 6.

By the time electrons emerge from the third lens, they perform everything a light beam performs in a light microscope. If only they could be made visible to the eye, the whole device would perform as an actual miscroscope. And indeed, nature was generous enough to furnish energy converters in the form of fluorescent materials, which become luminescent when struck by

* The electron beam is quite sensitive to even weak magnetic fields. Thus, for example, the earth's magnetic field and the field of the filament itself are sufficient to deflect the beam considerably. The whole microscope chamber therefore must be protected thoroughly with magnetic shielding (see Figure 8).

electrons. Such is, for example, Willemite (zinc orthosilicate). It is ground to a fine powder and deposited in a thin layer on the glass window. Its fluorescence distinguishes itself by the green color which nearly coincides with the zone of maximum sensitivity of the human eye.*

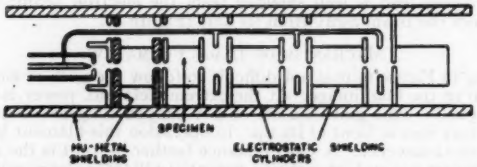

FIGURE 8. LOCATION OF MAGNETIC AND ELECTROSTATIC SHIELDINGS.

Thus, the electrons are finally allowed to impinge upon this "screen." The brilliance of fluorescence of the various elemental areas of the latter depends directly upon the amount of energy carried to them by the corresponding portions of the electron beam, so that less transparent areas on the specimen will look dark on the screen, while thinner sections will look brighter.

As a final magnifying stage, use has been made of ordinary glass eyepieces, or perhaps, for convenience, low-power binocular microscopes. Placed outside of the vacuum and independent of the electron optics, they furnish additional magnification of the electron image as well as a quick means of changing magnifications. By simply interchanging eyepieces additional magnification (4 × to 30 ×) is readily obtained.

It is well to observe at this point that the fluorescent screen ought to be sufficiently fine in grain structure to allow further magnifications. Indeed, a special technique of depositing screens from a thin suspension was developed for this purpose. Ball-milled particles of Willemite well under a micron in diameter and in a layer as little as 3 microns in thickness were sometimes sufficient to give a complete coverage of the glass surface. An electron image on such a screen can be magnified as much as 30 times before the screen structure affects the detail.

As a matter of further convenience, an external photographic camera is attached to make permanent records of samples when it is desirable. It is prefocused and is usually slipped on at the screen end after the eyepiece is removed (Figure 10). Photography is normally done at relatively low magnification for the sake of speed, since more brightness is available, permitting shorter exposures. Further magnification may then be obtained by ordinary photographic enlargements.

ESSENTIAL ACCESSORIES.

Having established the general form of electron optics for an electrostatic microscope, it is well worth taking a glance at the major requirements of a complete device, apart from its optics, with resulting essential components.

First, the fact alone of using electrons as a working medium stipulates several imperatives:

(1). Work must be done in vacuum.

(2). Power supplies must be provided in order to generate and control the stream of electrons:
   (*a*). Filament heating supply
   (*b*). High-voltage accelerating potential supply.

(3). Controls are necessary to manipulate the specimen and to adjust power supplies.

* It is also widely employed in other electronic devices which are perhaps better known to the public: cathode-ray tubes, "magic eyes," etc.

(4). Vibration elimination is imperative for best performance of the instrument. It is supplemented by good soundproofing and ventilation of the unit.

Taking up the first of the imperatives, it should be remembered that the purpose of microscopes is to examine diverse specimens. It seems inevitable, therefore, to use continuously running vacuum pumps to keep the microscope barrel evacuated as the samples are changed from time to time. The pumping system must be large enough to maintain vacua in the range of 10^{-4} to 10^{-5} millimeters of mercury, or better, necessary for undisturbed passage of electrons. At present it takes two pumps in series (Figure 9) to attain such pressures: one mechanical rotary pump and one "molecular" or diffusion pump. Air-cooled two-stage oil-diffusion pumps are used in these instruments.

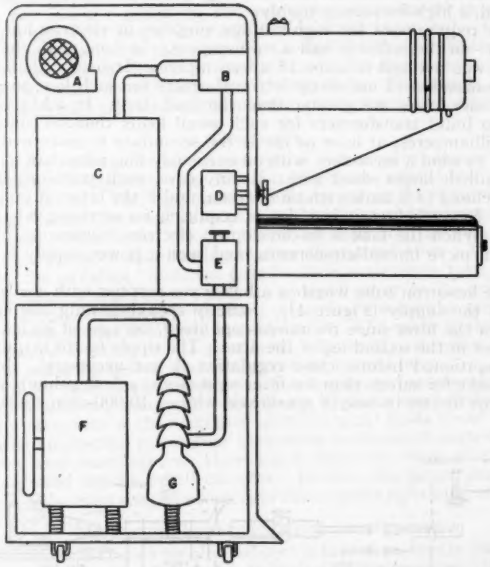

FIGURE 9. LAYOUT OF AUXILIARIES IN THE WAR MODEL CABINET.
A: Fan. B: Vacuum chamber. C: Power supply. D: Variac
E: Valve. F: Mechanical pump. G: Diffusion pump.

Continuously running pumps introduce a minor complication: whenever a specimen is changed, they must be either shut off or blocked off with a valve since the microscope barrel must be open to air. The valve method seems to receive general preference even though it involves additional equipment. The pumps are then left running and hot while "standing by" for the new specimen.

POWER SUPPLIES.

(1). The tungsten filament of the gun must be heated to a temperature of some 2800 C. in order to emit electrons at the desired rate. Lower temperature cathodes, such as oxide-coated or thoriated ones, are not suitable for this high-voltage operation since they suffer from positive ion bombardment. Thus, in spite of the relatively low electron flow, a considerable amount of power is

supplied to the filament. It varies between 15 and 25 watts, depending on filament construction. Eight-mil tungsten wire is employed, and must be replaced occasionally.

Two successful schemes were tried to supply the filament: (a) a 60-cycle transformer, specially built and insulated for 30,000 volts on the secondary; and (b) a high-frequency oscillator with an air-core transformer, insulated for 30 Kv. merely by adequate air spacing between the primary and the secondary. The latter costs less to build and makes use of standard parts. Its 6L6 oscillator may derive its d-c power directly from the low d-c source of the high-voltage supply. On the other hand, a 60-cycle transformer is sturdier and more controllable by means of a small autotransformer. Both schemes are equally good from the electron-optical standpoint.

(2). Thirty thousand volts are supplied to the anode of the gun. Again, two approaches were studied, both with equal success: first, a 60-cycle supply, and second, a high-frequency supply.

Current requirement for high-voltage supplies in electron microscopes is rather low—in the order of half a milliampere. In fact, with the latest gun designs it was reduced to some 15 microamperes. It seems, therefore, somewhat unreasonable to use 60-cycle transformers for such low power outputs since the core losses are greater than the load itself. In addition, it is not cheaper to build transformers for such small loads than to build them for several milliamperes, at least as far as the secondary is concerned. It would cost more to wind a secondary with an extremely fine wire than to use a more easily handled, larger sized wire. In any case, such transformers must be totally enclosed in a tank with oil or freon, and if the latter it must be under pressure. Nevertheless, it is a design requiring no servicing whatever, once installed. When the task is to develop an electron microscope, the electron optics is of more immediate concern, and such a power supply is a welcome adjunct.

A single kenotron tube wired as a half-wave rectifier with a π-section filter completes the supply (Figure 11). Strictly speaking, only one condenser is required in the filter since the microscope itself, because of its lenses, acts as a condenser in the second leg of the filter. The ripple factor is quite bad but, as was mentioned before, close regulation is not necessary. Resistors are inserted more for safety than for filtering reasons: a 5-megohm resistor serves as a current limiter in case of sparkover, while a 10,000-ohm resistor protects

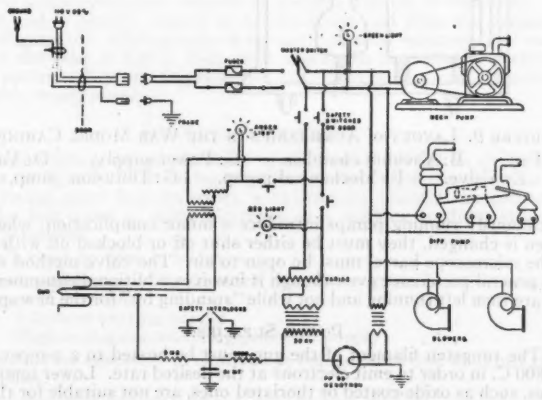

FIGURE 11. CIRCUIT DIAGRAM OF THE WAR MODEL.

the condenser from short-circuit discharges when the safety interlocks ground the high-voltage lead.

A voltage-doubler scheme was found to be more successful. The inverse peak voltages are only 30 Kv. compared to 60 Kv. for the previous scheme, the high-voltage transformer secondary is only 15 Kv., and small standard rectifiers (8013's) could be used in air. Only the high-voltage transformer with filament windings is then immersed in oil.

Still further refinement was sought in the high-frequency approach. This supply was built especially for the portable microscope as it seemed utterly inconceivable to incorporate 200 pounds of iron into a suitcase and still call it portable.

When finished, the high-frequency supply weighed less than 20 pounds and occupied only one-fourth of the space taken by the 60-cycle supply. It is quite straight-forward in its construction: an ordinary radio full-wave rectifier furnishes the low d-c power to the oscillator, made up of two 6L6 beam pentodes, which feed power into a 160 Kc. transformer coil. The latter is constructed especially for this purpose, having 15,000 volts in the secondary and is insulated for 30 Kv. from the primary. A voltage doubler scheme is used again to boost the rectifier a-c to 30,000 volts. Filtering is unnecessary because at such high frequencies the microscope itself serves as a capacity filter.

Controls.

Controls are essential in an instrument of this kind whenever the utmost in performance is required. The filament brightness must be adjusted to an optimum condition. The high voltage must be set at the desired level. The sample must be manipulated to focus it on the screen and to inspect the whole field. Finally, there must be a provision for inserting the sample into the vacuum chamber and withdrawing it after the examination. This is accomplished by the so-called "insertion gate," which is merely a tube leading into the manipulator compartment, with an airtight cover on its outer end. To insert the sample, this cover is removed (after first closing the vacuum valve), and the sample holder is slipped into the tube. The cover is then shut, and the microscope is ready to be evacuated. Normally, it takes about three minutes of pumping before the voltage can be turned on.

The number of controls was kept to the minimum because the chief asset of an electrostatic microscope is its simplicity. Opinion was too often expressed that many scientists in chemical and bacteriological fields dread the thought of operating an electron microscope because of intricacy of controls, operating procedures, and maintenance. Here was a chance to show that an electron microscope need not be at all complex. In fact, the latest portable model turned out to be even simpler to operate than a good light-optical microscope.

Vibration, Soundproofing, Ventilation.

It is very common for an uninitiated person to underestimate the importance of vibration in electron microscopy. Indeed, a vibration of, say, 0.00001 of an inch in amplitude is present in floors and walls of almost any industrial building, and it isn't even felt by the human body. But, if that much vibration of the sample inside of the microscope were allowed, at 10,000 × magnification it would register on the screen as 0.1 of an inch. Obviously, the image would be blurred. A design engineer handling a product with quite heavy rotary machinery inside is usually satisfied nowadays when the unit as a whole vibrates less than 0.001 of an inch. But, if the sample vibrated that much in the microscope, its amplitude would become about ten inches when fully magnified.

Thus, the standards of vibration elimination had to be revised. One can arrive at the maximum vibration amplitude by calculating backward from the permissible blur on the screen at maximum magnification. The human eye, at its best, can resolve the separation of from 0.003 to 0.005 of an inch between any two particles. At maximum magnification, therefore, a vibration below such amplitude will not be registered by the eye (nor by the instrument, since the aberrations will do the limiting of the resolution). Thus, two particles

separated by 0.005 of an inch can vibrate with a 0.001-inch amplitude and still be resolvable by the eye. If this is divided by 10,000, the permissible vibration amplitude is obtained: one ten-millionth of an inch.

Finally, a word about the soundproofing and ventilation. Noisy pumps and blowers are perpetual sources of annoyance in scientific laboratories. One well-known scientist has reported a noise measurement of over 100 decibels in one room with vacuum pumps. Unfortunately, there is no noiseless equipment on the market; so resort was made to soundproofing. It makes for comfortable operating conditions and undoubtedly adds to the efficiency of operators. By totally enclosing the noise-making machinery and by proper baffling, the noise level was reduced to compare favorably with that of household refrigerators.

Ventilation, too, is of more than secondary importance in keeping down ambient temperatures around the microscope barrel. It must be remembered that the electrostatic lenses are prealigned with extreme accuracy, similarly to lenses in light microscopes. This keeps the beam as nearly axial as physically possible. But as soon as an uneven temperature expansion takes place, there is a chance for warpage and therefore misalignment. Instances of noticeable warpage have been observed. In addition to some 30 watts being dissipated inside of the microscope itself, there is from 200 to 600 watts dissipation from the remaining equipment. It is very appropriate, therefore, to place a blower or two in strategic points to convect away all this heat as quickly as possible.

Conclusion.

This article has dealt chiefly with the ideas that guided the design of G-E electrostatic electron microscopes. In it, only brief mention has been made of how the application of these ideas actually materialized, and no discussion of lens aberrations has been included. Although mathematical studies have been made on electron optical lenses, the few attempts to obtain actual aberration corrections have not been very successful. Glass optics in this respect is far ahead of electron optics—even the cheapest microscopes have corrections for spherical and chromatic aberrations. Allegorically speaking, present-day electron microscopes are merely crude magnifying glasses stacked together to yield larger magnifications. Indeed, their development is still in the age of infancy. Before the development reaches the ripe age of glass optics the world will, no doubt, witness many spectacular strides in electron microscopy

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OUTBOARD DRIVE FOR BARGES.

This article describing the Murray and Tregurtha Company outboard drive units is reprinted from Motorship, November, 1944.

One of the outstanding developments resulting from war operations is the practical application of an idea that has been tried out in various forms in years gone by—the use of a portable outboard drive for temporarily powering barges and other non-propelled vessels of large size.

Early in the war it became apparent to the military authorities that the usefulness of shallow draft barges in landing operations could be greatly increased if a means could be developed for providing a portable propulsion unit similar to the widely used outboard motor, that could be readily mounted on a barge and moved from barge to barge as needed.

The Murray & Tregurtha Company was called upon to develop such a unit. The engineers of that organization tackled the problem and the resulting design was put into production within a short time. The initial experimental work was soon supplemented by trial in service under field conditions.

After the usual "bugs" were worked out the new propulsion unit found a wide variety of applications in war service. It has now become enough of a commonplace on the landing beaches throughout the world to permit us to make known its design and construction. Aside from the interesting things this propulsion unit has done in war service we believe that the readers of Motorship will be interested in it because of its post-war commercial implications.

The power unit consists essentially of a Diesel or gasoline engine driving a vertical shaft through bevel gears, and a propeller, driven from the lower end of the vertical shaft by a second set of bevel gears. This general arrangement is similar to the small outboard motors of which thousands are in use throughout the country. The principal differences arise from the fact that the Murray &,Tregurtha drive is produced in units of much greater power.

The construction and method of application will be made clear by the accompanying photographs and sketches. The engine is mounted on I beams and completely enclosed. The gear and propeller shaft casing assembly is attached to the after end of the engine base. At the forward end is a bracket for supporting the steering wheel.

The engine shaft is connected through a coupling to a spiral bevel pinion that meshes with a drive gear which in turn meshes with a pinion on the vertical shaft, the gears being enclosed in a housing. The vertical shaft passes down through a housing and connects with the horizontal propeller shaft through a bevel gear and pinion. The housing which supports the propeller shaft is integral with the housing for the vertical shaft. This housing assembly is attached to the gear housing but is free to rotate through 360 degrees.

The rotatable housing assembly is provided with a worm gear. The driving worm is connected by chains and a longitudinal shaft to the steering wheel on the forward end of the engine. This arrangement permits the propeller to be rotated in azimuth for steering.

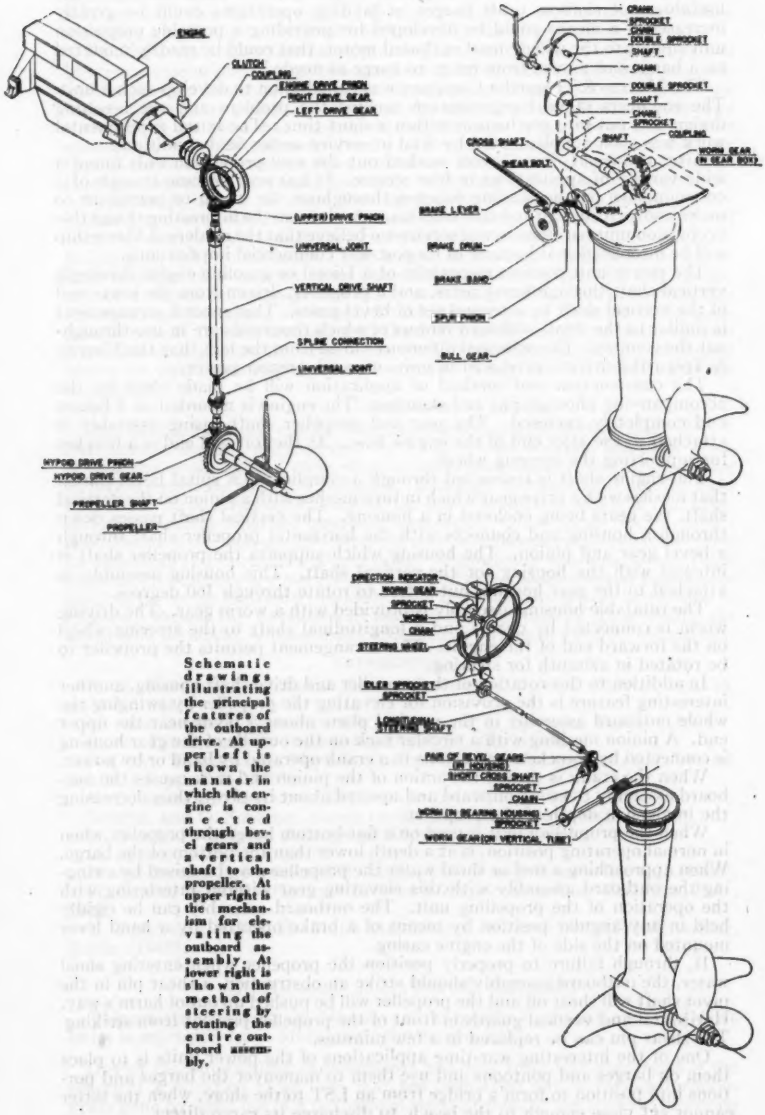
In addition to this rotation of the propeller and drive shaft housing, another interesting feature is the provision for elevating the propeller by swinging the whole outboard assembly in the vertical plane about a pivot near the upper end. A pinion meshing with a circular rack on the outside of the gear housing is connected by sprockets and chains to a crank operated by hand or by power.

When the crank is turned the action of the pinion and rack causes the outboard assembly to swing outward and upward about its pivot, thus decreasing the immersion depth of the propeller.

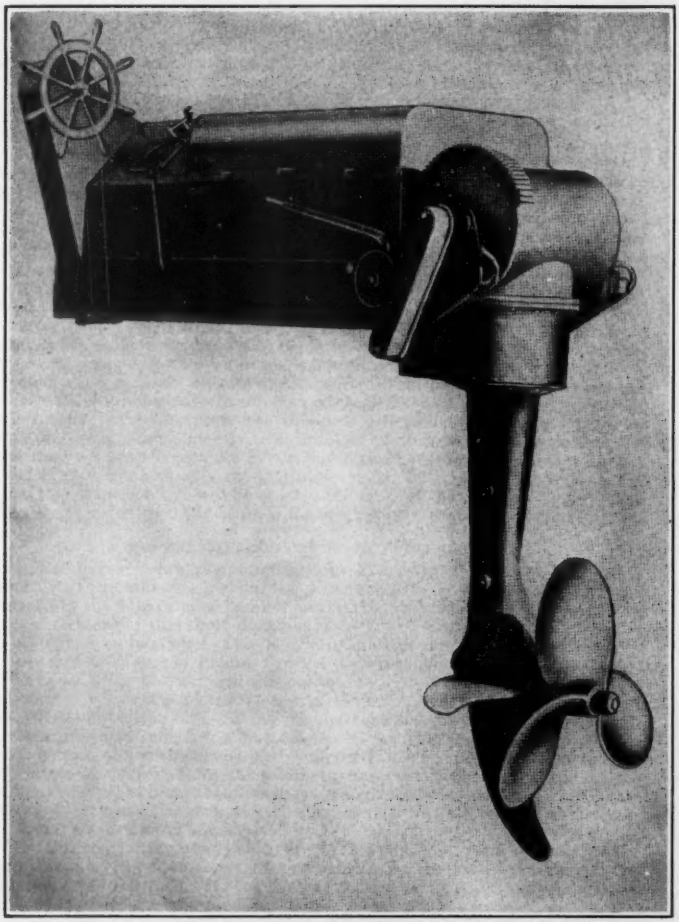
When the propulsion unit is used on a flat-bottom barge the propeller,when in normal operating position, is at a depth lower than the bottom of the barge. When approaching a reef or shoal water the propeller may be raised by swinging the outboard assembly with this elevating gear without interfering with the operation of the propelling unit. The outboard assembly can be rigidly held in any angular position by means of a brake operated by a hand lever mounted on the side of the engine casing.

If, through failure to properly position the propeller when entering shoal water, the outboard assembly should strike an obstruction, a shear pin in the pivot shaft will shear off and the propeller will be pushed up out of harm's way. Horizontal and vertical guards in front of the propeller prevent from striking The shear pin can be replaced in a few minutes.

One of the interesting war-time applications of the power units is to place them on barges and pontoons and use them to maneuver the barges and portions into position to form a bridge from an LST to the shore, when the latter cannot get close enough to the beach to discharge its cargo direct.



Schematic drawings illustrating the principal features of the outboard drive. At upper left is shown the manner in which the engine is connected through bevel gears and a vertical shaft to the propeller. At upper right is the mechanism for elevating the outboard assembly. At lower right is shown the method of steering by rotating the entire outboard assembly.



THIS DIESEL OR GASOLINE UNIT CAN BE ATTACHED TO THE BARGES QUICKLY AND EASILY.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

STEREOSCOPIC PHOTOGRAPHY.—This paper, by John T. Rule, describing the various methods of stereoscopic photography and projection, was contributed by the Committee on Education and Training for the Industries and presented at the Semi-Annual Meeting of the American Society of Mechanical Engineers, in June, 1944. Mr. Rule is chairman of the Section of Graphics, Massachusetts Institute of Technology. His paper was published in the November, 1944, issue of Mechanical Engineering.

While practically everyone is acquainted with stereoscopic photography in one form or another, to refresh the reader's memory on the basic principles of stereoscopic vision, I will state briefly the problem involved in order that he may have a clear understanding of what we are trying to accomplish.

Suppose one stood before a window without moving his head and closed the left eye. Then the right eye, if held still, could never be certain whether it was viewing a scene through the window or a perfect picture of the same scene on the window. Now if the left eye is opened and the right one closed, the same thing would be true. However, two interesting facts present themselves, (1) the picture seen by the right eye would be different from that seen by the left, and (2) it would overlap the same area. If the real scene were being viewed, each eye would see only its own picture, whereas if the pictures were being viewed, both eyes would see both pictures.

Now if each eye only sees its own picture, we naturally see it as in normal vision in three dimensions. In other words each eye receives a two-dimensional image. The brain interprets the differences between these two images in terms of depth. Consequently, the problem of stereoscopy is only this: To place the two proper pictures in the same place at the same time in such a way that each eye sees only the picture intended for it. Once this is done, the retinal image in each eye will be exactly the same as though the original scene were being viewed, and the brain will interpret it in exactly the same way.

From the Stereoscope to the Polarizer.

Originally there were two simultaneous efforts to do this; one by using mirrors, and the other by placing the pictures in the area near enough to the eyes so that the field of view had not yet started to overlap, and then enabling the eyes to focus at this short distance by means of lenses. This, of course, is the old parlor stereoscope. This had very obvious limitations, chief of which was the antisocial one of having to view a picture alone.

The next effort came from the desire to print. This was the so-called anaglyph in which the pictures were of different colors which were filtered through viewers of the same colors. Though this has grave defects, it has had some success in specific fields, notable in the printing of aerial photographs. I will mention only two defects of this method: (1) the difficulty of matching color filters to color dyes or inks without having a large percentage of the wrong wave lengths from the dyes pass through the filter and thus yield ghost images; (2) the obvious one, since color has been used to obtain the stereo, one cannot have colored stereos.

After this the art lay nearly dormant for a number of years waiting for the development of the obviously correct method, i.e., the use of polarized light. With the invention by E. H. Land of a polarizer that could be produced in quantity, the stereoscopic field immediately took on a new lease of life.

Development of the Vectograph.

The logical step was to project two pictures with polarizers in front of them, with axes perpendicular to each other, and to supply the audience with viewers similarly polarized. This double-projection method is still used exclusively when color is desired and is only gradually being superseded by the vectograph which enables us to use single instead of double projection.

With an eye to the movie industry, the avoidance of double projection, and the desire to have prints, the vectograph was developed by Mr. Land. This

enables us to have two pictures in the same place at the same time without interference. Vectographs have the two pictures, one on either side of a special sheet. The pictures are polarized within themselves, do not interfere, and can be made either as slides or prints. They represent an entirely new kind of photography for they are not images in black and white but images in terms of per cent of polarization. We view them through viewers and obtain pictures which inherently can be as good as those of normal photography. Vectographs are being made in color in the laboratory but have not yet been released publicly. I believe it is impossible to overemphasize the revolutionary character of the vectograph or its importance in the photographic field.

Mention may be made at this point that one very good method for limited use exists which does not require viewers. Of much greater importance, however, is the fact that the vectograph can be printed. Vectograph slides can be projected by any ordinary projection equipment making no change whatever except the use of an aluminized screen which happens to be cheaper than the usual beaded screens.

Striking results have been obtained from using polarized light in stereoscopy. The presence of depth has a very powerful appeal. In fact, Oswald Spengler, the most magnificent exaggerator of our time, claims very convincingly that the feeling for depth—I think he probably would use the word yearning for depth—is the key symbol of western civilization. The reader can draw his own conclusions as to what he might mean by that. It is a fact, however, that a three-dimensional picture has a remarkably fresh and permanent appeal to all of us. Furthermore, there isn't the slightest doubt that it makes many complex and difficult-to-understand pictures very simple and understandable. The latter point is clearly shown by aerial photographs.

Vectograph a Powerful War Tool.

The vectograph has become a powerful tool in this war. The ability of a group of officers to analyze vectographs together, which is difficult in a stereoscope into which only one individual can look, is of enormous value strategically.

In photographing machinery and machine parts, three-dimensional pictures have great value. Many intricate mechanisms are very difficult to analyze in two dimensions. Depth levels of separate parts have to be explained verbally with varying success in two dimensions but are perfectly obvious in three. The third dimension has a "separation" value which is of great importance.

Problems of Stereoscopic Photography.

The most interesting fact about stereoscopic photography is that the approximate size of the resultant image must be known before the pictures are taken. In ordinary photography, any size picture can be shown on any size screen. In stereoscopic photography, the distance between the two lenses, the interocular, is determined by the size of screen which is to be used or the size of print it is intended to make. In general we take three pictures of subjects such as these. These pictures will yield three pairs, one pair for making prints, the other two pairs for different size screens.

The wider the interocular that is used, the greater the depth that will be achieved for any given size image. To achieve a perfectly shaped image, the camera interocular dictates both the size of the resultant picture and the viewing distance. Any departure introduces distortions.

This may seem a limitation, but it actually introduces the opportunity to obtain some very interesting effects. Of course a flat picture has only one proper viewing point for any given size, although one can depart from this quite substantially before the distortions become annoying. Such distortions can be detected in stereoscopy simply by moving the head from side to side and noting the change in shape of the object.

Now the interesting fact is that we do not necessarily want a properly shaped image. Perhaps an exaggerated depth will be more effective, if so we can provide it. Needing to know how to achieve proper shape as a point of

departure, we use formulas for determining the proper interocular under any conditions.

Though these formulas are basic, each practitioner uses them to determine what interocular he should use and then departs from this interocular to suit his taste, either aesthetic or theatrical.

The possibilities are infinite, and I have no doubt that publications which approach photography as an art will soon be filled with erudite articles on the aesthetic effect of various interoculars. We shall probably run through the same sort of fashions in stereophotography as we have in flat photography viewed as an art.

At the present moment the uses of stereo in teaching have probably been given the most attention and will probably be of interest to the reader, for they present some very interesting techniques. Furthermore, this is my own field, and therefore the one I most enjoy discussing.

Use of Models and Stereoscopic Drawings.

In addition to straight photographs, a great deal has been done with models and with stereoscopic drawings. The latter have very powerful possibilities. In the former application, the Navy uses vectograph slides of models in teaching celestial navigation. Their value over actual models lies chiefly in the fact that they are quite large, can be produced cheaply in quantity, and can be transported from place to place in very small packages.

Another very fruitful field is that of mathematics. I have yet to find a student who is capable of seeing in three dimensions at all who hasn't had his attention captured by stereoscopic drawings far more than by any other means. Furthermore, the pleasure of three dimensions does not seem to dim with long acquaintance. Before closing we should mention the movies and touch briefly on some of the difficulties of stereoscopy.

Use by Motion-Picture Industry.

The vectograph should be the answer to the stereoscopic movie. The problems still to be surmounted are chiefly technical ones of registration, film lamination, and the like.

Insofar as the industry itself is concerned the only necessary changes are the use of double cameras, the use of aluminized screens, and the problem of persuading the audience to use viewers. Of course many movie techniques will have to be revised. Backdrops and dodges of that sort and existing film libraries will all have to be abandoned. Probably a new set of stars will be necessary since photogenicity in two dimensions doesn't guarantee it in three. The results are frequently quite different.

None of these obstacles is insurmountable. The technical ones are in the process of being liquidated. The viewer problem is simply one of habit. Probably you will own your own viewers or pay five cents extra for admission.

The chief problem of stereoscopy, other than the eternal one of interoculars, is that of eye strain. This is chiefly a problem of care; the elimination of verticals, the avoidance of too great a separation between views, and the like. There is of course inherently a difference between viewing a scene and viewing a stereo in that in stereo the eyes are constantly focused for the distance to to the screen while the convergence changes.

Different individuals differ in their ability along these lines, but it is perfectly possible to hold pictures well within the strain point for all but those of the poorest vision. If an individual cannot see the stereo at all, and there are quite a number who cannot, he need only wear spectacles with both polarizers oriented for one picture, and he will simply see a flat movie.

Another interesting phenomenon involves the limits of stereo vision. It would seem that an object 1 foot deep, viewed from 1 foot would appear to have more depth than one of 6 inches viewed from 6 inches. But this is deceptive, for an object 1 mile deep viewed from 1 mile appears to have no depth at all because it is beyond the limits of stereovision. Again, as one moves back from the screen, a three-dimensional scene seems to get deeper, but by continuing to move back the ability to detect depth decreases with

increasing rapidity, and though the scene is deeper on optical principles, one is no longer able to detect it. In fact at 100 feet, stereo begins to get feeble. This can be avoided by bringing the image forward from the screen, but the accommodation-convergence problem soon arises when this is done. This problem has not been fully investigated, but it would seem to dictate rather small stereotheaters.

ORIGIN OF INTERCHANGEABLE PARTS.—Mr. Thomas Coulson, Director of Museum Research, The Franklin Institute, describes the earliest known uses of interchangeable parts. This practice, the essence of mass production, was apparently first employed in the manufacture of firearms. The following article is reprinted from the November, 1944, Journal of the Franklin Institute.

Through the generosity of the late Ralph H. North, The Franklin Institute Museum received a handsome collection of the pistols and rifles made during the years 1799 and 1852 by his great-grandfather, Simeon North, the first official pistol maker to the United States. The case of weapons is surrounded by an interest which goes far beyond that of the arms collector, for some of the items are milestones along the early path of progress made in manufacture of interchangeable parts. Controversy will continue to rage around the relative claims of Simeon North and Eli Whitney to be granted the honor of being the originator of the system, which is the essence of mass production. While no pretense is made to weigh the claims of the two pioneers, this paper attempts to set forth more fully than has been done before the circumstances of the establishment of that system.

It was not entirely by chance that the manufacture of interchangeable parts had its genesis in the United States, nor that the pioneers were the nation's gunsmiths. The system suggests itself in operations which require the repetition of a uniform series of more or less simple movements. Such repetitive production was repugnant to the American worker of the eighteenth century, who was accustomed to more varied pursuits and who was temperamentally too impatient to follow a routine. A secondary influence in the adoption of devices for the replacement of handiwork was the scarcity of skilled labor in the country and the high wages demanded by those who had acquired a skill in mechanical craftsmanship.

Yet, in spite of these forces, there was no stimulation to the invention of the necessary machinery, except where the demand for the product was large enough to justify its installation. There were relatively few uses for articles made of metal. Aside from castings, the only market for metal products of uniform shape was in common tools, such as axes, scythes, etc. The most elementary stage in the mechanical production of uniform metal parts was entered when a machine was invented, shortly before 1790, which automatically cut plates into nails. The next stage was the development by the gunsmiths, and it is a singular coincidence that, of all the typical products now produced under the system of interchangeable parts, weapons and clocks are the only ones that ante-date the system itself.

Although the system is inseparably associated with this country, and is called the "American System" abroad, the first suggestions for its use came from France. At least two early attempts to manufacture muskets from interchangeable parts were made in France during the eighteenth century. The first, in 1717, is practically unknown, and the second might have suffered a similar oblivion had it not attracted attention in an unexpected quarter. During the time he was Minister to France, Thomas Jefferson wrote to John Jay, under the date August 30th, 1785, a letter which contains the following passage:

"An improvement is made here in the construction of muskets, which it may be interesting to Congress to know, should they at any time propose to procure any. It consists in the making every part of them so exactly alike, that what belongs to any one, may be used for every other musket in the

magazine. . . . Supposing it might be useful in the United States, I went to the workman. He presented me the parts of fifty locks taken to pieces, and arranged in compartments. I put several together myself, taking pieces at hazard as they came to hand, and they fitted in the most perfect manner. The advantages of this, when arms need repair, are evident. He effects it by tools of his own contrivance, which, at the same time, abridge the work, so that he thinks he will be able to furnish the musket two livres cheaper than the common price."[1]

The name of the mechanic was revealed in a later letter to be Le Blanc, and he extended his system to the standardization of manufacturing the barrel, mounting, and stock. Jefferson was much impressed by Le Blanc's achievement, for he brought it to the attention of the Governor of Virginia in another letter, and years later he recalls the incident in a letter to James Monroe, in which he wrote: "I endeavored to get the United States to bring him over, which he was ready for on moderate terms. I failed and I do not know what became of him."[2]

The indifference of the home authorities to Jefferson's suggestion can only be attributed to the incurable reluctance of the American people to make advance preparation for an outbreak of hostilities. Jefferson was a man of many parts. He was a statesman of superior qualities who demonstrated in these letters a realization of the official responsibility to have at hand the adequate means of implementing national policies. He also possessed sufficient mechanical ability to perceive that where a gun was made of parts, each made by hand and eye, without gauges, and fitted to its neighbors, the loss or deformation of a single part rendered the gun useless for a considerable time. This may not have been a grave matter when each individual was supposed to furnish his own weapons, but when a national army was in question the matter assumed a very serious aspect. In 1812, the British government, on the authority of Eli Whitney, had 200,000 muskets awaiting repair of some defects,[3] so that the desire for an interchangeable parts system of production must have been acutely felt. It is perhaps necessary to point out how exasperating the dissimilarity of weapons must have been to George Washington, whose men had to carry individual bullet moulds because of variations in the calibers of their muskets.

If the authorities were unwilling to employ Le Blanc on Jefferson's recommendation, they certainly displayed no reluctance to adopt his system when the need arose for the expansion of gun-making. Because of the threat of impending war with France, the Congress, in 1798, passed an act appropriating $100,000 for the purchase of arms and ammunition. Two of the contracts recorded in the fulfillment of this legislative act are of the utmost importance in the origin of manufacture of interchangeable parts.

One of these contracts went to Eli Whitney, who had already invented the cotton gin, which was to have such a profound economic influence upon our civilization. Unfortunately, the unsatisfactory condition of the patent situation offered him no protection and he lost, rather than gained, money as the result of his revolutionary invention. In order to find a means of livelihood he had decided to enter the gunsmith's field. Having received his contract for 10,000 muskets (one quarter of those required) he built a small plant at Whitneyville, near New Haven, Conn., which was operated by water power. Two years were consumed in building the plant and in furnishing it with the necessary machinery. Just what that machinery was may be conjectured from a letter he wrote to the Secretary of the Treasury in 1798 soliciting the contract. He wrote:

'I should like to undertake the manufacture of ten to fifteen thousand stand of arms. I am persuaded that machinery moved by water, adapted to this business would greatly diminish the labor and greatly facilitate the manu-

[1] The Writings of Thomas Jefferson, edited by H. A. Washington, New York, 1853, vol. i, p. 411.
[2] Writings of Thomas Jefferson, edited by P. L. Ford, New York, 1887, vol. viii, p. 101.
[3] Letter quoted in Blake, History of Hamden, Conn., New Haven, 1888, p. 133.

facture of this article. Machines for forging, rolling, floating, boring, grinding, polishing, etc., may all be made use of to advantage." [4]

The second contract of significance was awarded to Simeon North, a practicing gunsmith of Berlin, Conn., which was for 500 horse pistols, a number which was subsequently raised to 1,500 two years later. North's entire contract was completed and the pistols delivered before Whitney had turned out a musket. In view of the controversy which arose over priority in the manufacture of interchangeable parts, it should be mentioned that none of these early contracts makes mention of their use. It is, however, apparent that North was early in this field, for he describes the subdivision of labor in a letter written to the Secretary of the Navy, written on November 7th, 1808, in which he writes:

"To make my contract for pistols advantageous to the United States and to myself I must go to a great proportion of the expense before I deliver any pistols. I find that by confining a workman to one particular limb of the pistol until he has made two thousand, I save at least one quarter of his labor, to what I should provided I finish[d]. them by small quantities: and the work will be as much better as it is quicker made.

"To proceed in this way I must purchase the most of my Stock and Bestow a great proportion of the labour upon it before I can finish a pistol . . . I have seventeen thousand screws and other parts of the pistols now forg[d]. and many parts nearly finished and the business is going on pretty lively." [5]

It has been stated that this is the first documentary proof that the system of manufacturing interchangeable parts had been placed in operation. But, it must be pointed out that Whitney claimed to have been performing this process as early as 1800, when he first began work on muskets. This claim rests upon a letter which he wrote in the year 1812, and in which he states:

"The subscriber begs leave further to remark that he has for the last 12 years been engaged in manufacturing muskets; that he has now the most respectable private establishment in the United States for carrying on this important branch of business. That this establishment was commenced and has been carried on upon a plan which is unknown in Europe, and the great leading object of which is to substitute and correct effective operations of machinery for that skill of the artist which is acquired only by long practice and experience; a species of skill which is not possessed in this country to any considerable extent." [6]

This claim is substantiated by Captain Decius Wadsworth, who wrote to the Secretary of the Treasury in 1800 in the following terms:

"Where the different parts of the lock are each formed and fashioned successively by a proper machine, and by the same hand, they will be found to differ so insensibly that the similar parts of different locks may be mutually substituted. The extending of this principle to all parts of the musket has been a favorite idea with Mr. Whitney from the beginning." [7]

Finally, in Jefferson's letter to Monroe, already quoted, there appears additional corroboration, for he says in speaking of Whitney, "He has invented moulds and machines for making all the pieces of his locks so exactly equal that to take 100 locks to pieces and mingle their parts and the 100 locks may be put together by taking the pieces which come to hand."

There can be little doubt that Whitney experienced no small difficulty in completing his first contract. He and fourteen other contractors were notified by the Purveyor of Supplies that, as the stipulated time for the delivery of the muskets had expired, they were granted ten weeks in which to comply with its terms or suffer their contracts to be cancelled. Whitney was actually engaged over a period of eight years in fulfilling his contract for 10,000 muskets. The delay was not exclusively due to the difficulties he was encountering in the designing and making of machines to accomplish the various tasks, because,

[4] New Haven Colony Historical Society Papers, vol. v, p. 117.
[5] North, S. N. D., and R. H. Simeon North: first official pistol maker of the United States, Concord, 1913, p. 64.
[6] New Haven Colony Historical Society Papers, vol. v, p. 122.
[7] Blake, p. 296.

THE
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in 1801, he saw the French Model 1777 musket and was so impressed by its superiority over the Model 1763, which had been contracted for, that he suggested changes of fabrication that would improve it. His suggestions were adopted by the Ordnance officers, and he finished the balance of his 1798 contract with this improved model, which undoubtedly implied a certain amount of retooling.

The astonishing thing about his solicitation of a contract to manufacture muskets is not that he should have contemplated entering the field of the gunsmith, in which he was wholly inexperienced, but that he should have ventured into this strange craft with a system of manufacture that was entirely novel.

It is to be regretted that Whitney's contribution to the introduction of interchangeable parts has not been so fully and so dutifully described as was Simeon North's share in the achievement. There seems no doubt that he was confronted with numerous obstacles which tried his patience and tested his ingenuity. Nor does it appear that the system he had adopted enabled him to manufacture at reduced cost in comparison with competitors. His reputation as a mechanic was too firmly established, however, to permit the authorities to dispense with his services when his deliveries and his price were not quite up to standard. In the Ordnance Department's correspondence there is a revealing letter written by Callender Irvine, the Purveyor of Supplies, who was trying to reduce to order the chaos created by the private contractor system. Writing to the Secretary of War on January 12th, 1814, he declares:

"Tis true a contract was entered into with Eli Whitney dated 18th of July 1812 for 15,000 Muskets with Bayonets and Ramrods complete at $13 Dollars per stand but from the specimen I have seen of the muskets he intended to deliver, not being any better than those delivered at $10.75/100 Dollars and his refusal to have them made superior to those; as well as from his not having delivered any Arms altho his contract required him to deliver 500 stands on or before 1st of May 1813 he has been notified that his contract is at an end and directed to return the amount advanced to him." [8]

However, the Secretary of War had a better appreciation of Whitney's ability and methods, and declined to permit the cancellation of the contract. This did not dispel Irvine's apprehensions of Whitney for, when the manufacturer notified the Purveyor that he had 500 muskets ready for inspection in the following year, Irvine was disturbed by the vagueness of Whitney's contract and directed the Inspector of Arms to select three of the muskets, "let them be as nearly alike as may be in all their parts as they are intended to govern in Inspection of Mr. Whitney's future deliveries."

The vagueness of Whitney's contract (and it was vague) was certainly remedied in subsequent contracts, and it is through Irvine's laudable intention of drawing up a more satisfactory contract that we have the first mention of the weapon being made from interchangeable parts. As we have shown from various selections from the correspondence of the times, Whitney and North were both engaged in this system of manufacture. During the time he was Purveyor, Tench Coxe had encouraged it, but his successor, Callender Irvine, had small respect for Coxe and none whatever for the men to whom he awarded contracts. He was continually at war with the private manufacturers, hurling threats of suits and cancellations in his endeavors to obtain a satisfactory discharge of contractual obligations. He, too, must have realized the great advantages in the new system, for within a year of assuming office Irvine found a French musket which pleased his exacting fancy, and having secured the War Department's approval of the model, he used it as the standard for the next contracts. In a letter to his four deputy commissioners of supply regarding the manufacture of the muskets, he says: "It is intended that the locks, bands, plates, and screws of one Musket may be fitted to any other musket of 100,000, all the component parts being made precisely on the same Models." [9]

[8] Hicks, Major J. E., Notes on United States Ordnance, Mount Vernon, N. Y., 1940, vol. ii, p. 45.
[9] Hicks, vol. i, p. 44.

Accordingly, North's contract in 1813 contains a clause which extends the application of interchangeable parts to the manufacture of pistols, so that the system appears now to have met with general acceptance. The same clause stipulates that, with each 100 pistols delivered, the manufacturer was to furnish a specified number of spares for those parts which were most subject to fracture or deformation.

However, the idea of specialization had not entirely been obliterated from the official mind. In order to obtain a more reliable water supply for his power, and to extend his manufacturing accommodation so that he could undertake the larger orders he was receiving from the Government, North had moved into a new building at Middletown, upon which he had spent a considerable sum of money. It would seem that the pistol contracts were insufficient to maintain the large staff of workmen he assembled there, because he was impelled to solicit a contract for muskets or rifles. Decius Wadsworth (now a Colonel of Ordnance), who had enthusiastically welcomed Whitney's system of interchangeable parts in an industry where Whitney had no experience whatever, now doubted the wisdom of confiding the making of rifles to a man who had specialized in making pistols. However, the Colonel's fears proved to be unfounded when North was awarded a contract in 1823 and demonstrated his proficiency by fulfilling its terms in one year under the stipulated time, which was something of a rarity among private arms contractors, who were always behind in their deliveries.

It is not inconceivable that this proof of plant efficiency induced the Government to grant him other contracts against the advice of one official armorer. This was in 1828, when the new Hall Rifle went into production. The wording of this contract is important since it marks a further step in the progress of the manufacture of interchangeable parts. After the now commonplace clause providing that all the component parts shall be interchangeable, the contract adds: "And also that the component parts may be exchanged in a similar manner, with the rifles made, or making, at the National Armory. The said exchange to be made without impairing in the least the efficiency or perfection of the Arms, which are thus composed of exchanging parts."

Captain John H. Hall, who was then assistant armorer at Harper's Ferry national armory, did not like this provision in a private contractor's arrangements, and prophesied all manner of evils would arise from it in making the rifle he had invented. Hall was a disciple of Whitney and North in the manufacture of interchangeable parts, for he had resolved to institute the system for the manufacture of his rifle. In some extraordinary manner, he has become credited in some quarters as the originator of the system. He did not even introduce the system into the national armories. In the year 1824, one hundred rifles had been brought together from the different armories and makers, broken down, and re-assembled at random.[10]

However, it is obvious that Hall contributed to the progress of the system, for he built special machines and tools, several of which he patented. However, his methods do not appear to have been as efficient as those of Simeon North. For, in the year 1836, the cost of making a Hall Rifle at Harper's Ferry was $21.13, whereas North was paid only $17.20 for the same rifle.

By this time, it may be acknowledged, the practice of manufacturing interchangeable parts had passed from the experimental stage and was universally accepted, in the arms industry, at least. It is difficult in our day to realize the immensity of the obstacles which had to be overcome by those pioneers who had nothing but their imagination to guide them. Everything was lacking—shops, materials, mechanics. Blacksmiths and an occasional coppersmith were the only workmen who could be engaged to make a specific tool, and they were likely to produce something with a poor edge and worse temper. Nor should we overlook the amazing isolation of the specialized craftsmen, probably the outcome of the guilds for preserving the "mystery" of manufacture. This isolation is very important, for its existence contributes substantially to the magnitude of the task confronting North and Whitney. For example, clockmakers had been able to make an instrument of such intricacy that it not

[10] Newcomen Society Transactions, vol. xvii, 1936, p. 170.

only indicated accurately the passage of hours, minutes, and seconds, but also the days of the month, the phases of the moon, and the movements of the known planets. As an artistic concession to this accumulation of scientific craft, they not infrequently introduced mechanism for playing musical selections and for controlling the actions of a group of marionettes. Yet, at the time these accomplishments were becoming relatively common, James Watt could not find anyone who could bore a cylinder sufficiently accurately to make a piston steam-tight.

When Whitney and North began to make muskets and pistols for the Government, there were very few machine tools in existence and few mechanics to whom they could turn for assistance. Maudsley was working upon the slide lathe in England, and there appears to have been some contemporary invention along similar lines in this country. Sylvanus Brown of Pawtucket is said to have invented a slide rest in 1791, and to have used it for cutting wrought iron screws for sperm oil presses. Jigs, too, had tentatively made their appearance in the textile industry. But this left the pioneers Whitney and North with a vast field of invention to cover before they could begin production.

Priority of invention is likely to remain in dispute by their supporters, but it seems improbable that the two men, living and working within twenty miles of each other, engaged in closely related pursuits, competing for the same contracts, and working through the same Government officials, should be unacquainted with what was going on in each other's plant. It would be wise to refrain from advancing too urgently the efforts to differentiate between the claims of the two men.

It would be an overestimate in the genesis of the system to say that either Whitney or North in the beginning surpassed a general concept of the problem of the manufacture of interchangeable parts. The process must have undergone much development and revision at their hands, and did not reach its full primary accomplishment much before 1830. But the achievement in that short time of thirty years is remarkable, not only in invention but in overcoming the inevitable inertia, opposition, and scepticism which obstructs all revolutionary proposals.

Colonel North never filed a patent, not even for the improvement of the firearms he was making, but his family have maintained the tradition, which may be true, that the filing jig was invented by his son Selah. They claim further[11] that the first milling machine was made and used in the North factory. Whitney constructed a milling machine in 1818, which is now treasured by Yale University, but the milling of irregular parts did not come until after 1840. During the years 1817-22 there came from various sources the introduction of forging in hand dies, barrel turning by machinery, and the automatic lathe for gunstocks. Receiving gauges were used in North's plant in Middletown after 1829, and Hall had already begun to use the drop hammer with dies at Harper's Ferry in 1827.

Thus, the elimination of handwork and the substitution of semi-automatic machinery was firmly established in the arms industry before the middle of the century. A contemporary journal[12] declares that 100 different machines were employed in the armories of the United States. These machines are described as self-acting and so automatic that several units could be supervised by a single workman.

The security afforded by governmental contracts and the willingness of the authorities to subsidize private contractors, undoubtedly contributed greatly to the promotion of the manufacture in the arms industry, but this detracts in no way from the abilities of the two pioneers, Eli Whitney and Simeon North. They pointed the way, they laid the road which succeeding generations were to tread. Others were not slow to follow their example. As soon as it became possible to substitute brass for wood in clock parts, the clock industry underwent a revolution by the introduction of interchangeable parts; and new industries which sprang up, like the manufacture of sewing machines, the harvester, and the typewriter, all adopted the system from their inception.

[11] North, p. 84.
[12] Farmer and Mechanic, vol. ii, Sept. 14, 1843, p. 440.

CHEMICAL PROPERTIES OF PLASTICS.—The chemical properties of plastics are of the greatest concern in the design of parts. W. S. Larson, of the Plastics Department of the General Electric Company, describes the effects of various reagents on the appearance, strength, weight and dimensions of nine representative plastic materials. Mr. Larson's article is reprinted from Product Engineering, December, 1944.

Those properties of plastics concerned with the ability or the inability of a given material to enter into a chemical reaction are known as chemical properties. Thus, they are distinguished from the physical properties associated with electricity, heat, light and sound.

From a design standpoint, the "inability" to enter into a chemical reaction—the chemical resistance, in other words—of the plastic is of greatest concern. Study of this property shows that there are phenomena involved which are not part of a chemical reaction but which are so closely associated with it that a distinction is difficult. Typical of these are moisture absorption, solvent action, aging and weathering, taste and odor characteristics and fungi resistance. Although these characteristics may not come under the formal definition of chemical properties it is, nevertheless, the most convenient and the most logical place to discuss them.

From a theoretical standpoint, pure water could have the following effects on a plastic:

1. Enter the material by capillary action and diffusion in a purely mechanical manner.

2. Dissolve or partially dissolve one or more constituents of the material by solvent action.

3. Enter into a chemical reaction, such as hydrolysis, with the material to form one or more new materials.

These actions may go on singly or simultaneously, and the rate at which they proceed will be affected by temperature and pressure.

In a similar manner, all of the chemical reagents considered here, whether pure or in a water solution, will affect the plastic material in much the same way. Thus, a problem involving chemical resistance should be analyzed for each type of effect and for each reagent involved. The tendency of a particular reagent to shrink or to leach a plastic sample can be offset by the water in which the reagent is dissolved. It is important to evaluate these test results without forming erroneous conclusions.

From the designer's viewpoint, the most practical measuring sticks of chemical resistance are the effects of the reagent on weight, dimensions, appearance and mechanical strength. More specialized applications, such as the effect on electrical properties, haze value and abrasion resistance, are also frequently of importance. These must necessarily be tested individually. The change in weight is usually irrelevant in actual design and service, but this increase or decrease is often a good indication of the over-all effect of the reagent.

The tentative test standard of the A.S.T.M. for measuring chemical resistance involves the immersion of a strip of the material 3x1x⅛ inches or a molded disk 2 inches in diameter and ½ inch thick in the reagent for 168 hours at 25 to 30 degrees C. The standard and supplementary reagents that have been selected are listed in the accompanying table. They are representative of many of the service applications of plastics and are also representative of many types of chemicals.

Although the data determined from this test and listed in the table may be consistent and accurate in its particular field, the A.S.T.M. recognizes the limitations of the test and recommends that the results be used only for comparison or for the selection of likely materials for further test. The following conditions are typical of those which may radically change the chemical resistance of a particular material to a reagent:

1. The reagent may be more active in higher or lower concentrations.

2. The effects may be advanced or retarded by changes in temperature or pressure or by the effect of a catalyst or sunshine.

Effects of Various Chemical Reagents at Room Temperature

	Molded Phenolic, General Purpose				Laminated Phenolic, Paper Base				Molded Urea				Cast Methyl Methacrylate			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
ercent sulfuric acid	+M	+M	A	Y	+N	+M	A	Y	+N	+N	A		+N	+N	N	X
ercent sulfuric acid	+M	+M	A	Y	+N	+M	A	Y	+N	+N	A		+N	+N	N	X
ercent sodium hydroxide	+E	+E	E	Z	+E	+E	E	Z	+N	+N	N		+N	+N	N	X
ercent sodium hydroxide	+M	+M	A	Y	+M	+M	A	Y	+M	+N	N		+N	+N	N	X
ercent ethyl alcohol	−N	+N	N		+N	+M	N		−N	+N	N		+E	+E	A	Z
ercent ethyl alcohol	+N	+M	N		+N	+M	N		+M	+N	N		+M	+M	A	Z
one	−N	+N	N		+E	+E	A		−N	−N	N		D	D	D	Z
l acetate	−N	−M	N		+N	+N	N		−N	−N	N		D	D	D	Z
lene dichloride	−N	+M	N		−N	+N	N		−N	−N	N		D	D	D	Z
on tetrachloride	N	+N	N		+N	+N	N		+N	+N	N		−E	−M	A	Y
ene	+N	+N	N		+N	+N	N		+N	+N	N		D	D	D	Z
ane	−N	+N	N		N	N	N		−N	+N	N					
ercent sodium chloride	+N	+N	N		+M	+M	A		+M	+N	N		+N	−N	N	
lled water	+N	+N	N		+M	+M	N		+M	+N	N		+N	+N	N	
ercent nitric acid	+M	+M	A	Y	+M	+M	A	Y	+M	+N	A		+N	+N	N	X
ercent hydrochloric acid	+M	+M	A	Y	+M	+M	A	Y	+N	+N	A		+N	+N	N	X
ercent acetic acid	+M	+M	N		+M	+M	A		+N	+N	N		+N	+N	N	
acid	+N	N	N		+N	+N	N		+N	+N	N		+N	+N	M	
onium hydroxide	+M	+M	C		+M	+M	A		+M	+N	N		+N	+N	N	
cent sodium carbonate	+M	+N	N		+M	+M	C		+M	+M	N		+N	+N	N	
cent hydrogen peroxide	+M	+N	N		+M	+M	N		+M	+N	C		+N	+N	N	

(1) Weight
N – Negligible change; under 1 percent
D – Dissolves
M – Slight or moderate change
E – Extreme change

(2) Dimensional
N – Negligible change; under 1 percent
D – Dissolves
M – Moderate change
E – Extreme change

	Polystyrene				Vinyl Chloride–Acetate Copolymer				Cellulose Acetate				Cellulose Nitrate				Butyl Cellu			
(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)		
X	+N	+N	N	N	+N	−N	N	N	+N	+N	A	X	+N	+N	N	X	+N	+N		
X	+N	+N	N	N	+N	+N	N	N	+N	+N	A	X	+N	+N	N	Y	+N	+N		
X	+N	+N	N	X	+N	−N	N	X	+N	+N	A	Y	−N	−N	A	Y	+N	+N		
X	+N	+N	N	X	+N	N	N	N	+N	+N	A	X	+N	−N	A	X	+N	+N		
Z	+N	+N	N	N	N	N	N	N	+N	+N	D	Z	A	D	D	Z	D	D		
Z	+N	+N	N	N	+N	N	N	N	+N	+N	D	Z	+N	+N	N	Z	+N	+N		
Z	D	D	D	Z	D	D	D	Z	D	D	D	Z	D	D	D	Z	D	D		
Z	D	D	D	Z	D	D	D	Z	D	D	D	Z	D	D	D	Z	D	D		
Z	D	D	D	Z	D	D	D	Z	+N	+N	D	Y	+N	+N	D	Y	D	D		
Y	D	D	D	Z	+N	+N	N	N	+N	+N	N	N	+N	+N	N	N	D	D		
Z	D	D	D	Z	+N	+N	N	Z	+N	+N	N	Y	+N	+N	D	Y	D	D		
	+N	D	N	Z	−N	−N	N	Y	−N	+N	N		−N	−N	N		+N			
	+N	+N	N		+N	−N	N		+N	+N	N		+N	+N	N		+N			
	+N	+N	N		+N	+N	N		+N	+N	N		+N	+N	N		+N			
X	+N	−N	N	N	+N	+N	N	N	+N	+N	N	X	+N	+N	N	X	+N			
X	+N	+N	N	N	+N	−N	N	N	+N	+N	N	Y	+N	+N	N	Y	+N			
	+N	−N	N		+N	−N	N		+N	+N	A		+N	+N	N		+N			
	+N	+N	N		+N	−N	N		+N	+N	N		+N	+N	N		Z			
	+N	+N	C		+N		N		+N	+N	A		−N	+N	A		+N			
	+N	+N	N		+N		N		+N	+N	A		+N	+N	N		+N			
	+N	−N	N		+N	−N	N		+N	+N	N		+N	+N	N		+N			

(3) Appearance
N – Negligible change
C – Discolored, dulled or yellowed
A – Attacked and roughened
D – Dissolved

(4) Dimension
N – Negligible loss
X – 0 to 20 percent loss
Y – 20 to 50 percent loss
Z – 50 to 100 percent loss

Effect of Various Chemical Reagents on Representative Plastic Materials

	Molded Phenolic, General Purpose				Laminated Phenolic, Paper Base				Molded Urea				Cast Methyl Methacrylate				Polystyrene			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	+M	+M	A	Y	+N	+M	A	Y	+N	+N	A		+N	+N	N	X	+N	+N	N	
	+M	+M	A	Y	+N	+M	A	Y	+N	+N	A		+N	+N	N	X	+N	+N	N	
xide	+E	+E	E	Z	+E	+E	E	Z	+N	+N	N		+N	+N	N	X	+N	+N	N	
xide	+M	+M	A	Y	+M	+M	A	Y	+M	+N	N		+N	+N	N	X	+N	+N	N	
	–N	+N	N		+N	+M	N		–N	+N	N		+E	+E	A	Z	+N	+N	N	
	+N	+M	N		+N	+M	N		+M	+N	N		+M	+M	A	Z	+N	+N	N	
	–N	+N	N		+E	+E	A		–N	–N	N		D	D	D	Z	D	D	D	
	–N	–M	N		+N	+N	N		–N	–N	N		D	D	D	Z	D	D	D	
	–N	+N	N		–N	+N	N		–N	–N	N		D	D	D	Z	D	D	D	
	N	+N	N		+N	+N	N		+N	+N	N		–E	–M	A	Y	D	D	D	
	+N	+N	N		+N	+N	N		+N	+N	N		D	D	D	Z	D	D	D	
	–N	+M	N		N	N	N		–N	+N	N		+N	–N	E		+E	D	E	
le	+N	+N	N		+M	+M	A		+M	+N	N		+N	+N	N		+N	+N	N	
	+N	+N	N		+M	+M	N		+M	+M	N		+N	+N	E		+N	+N	N	
	+M	+M	A	Z	+M	+M	A	Y	+M	+N	A		+N	+N	N	X	+N	–N	N	
rid	+M	+M	A	Y	+M	+M	A	Y	+N	+N	A		+N	+N	N	X	+N	+N	N	
	+M	+M	N		+M	+M	A		+N	+N	N		+N	+N	N		+N	–N	N	
	+N	N	N		+N	+N	N		+N	+N	N		+N	+N	N		+N	+N	N	
	+M	+M	C		+M	+M	A		+M	+N	N		+M	+N	N		+N	+N	C	
te	+M	+N	N		+M	+M	C		+M	+M	N		+N	+N	N		+N	+N	C	
ide	+M	+N	N		+M	+M	N		+M	+N	C		+N	+N	N		+N	–N	N	

(1) Weight
- Negligible change; under 1 percent
- Dissolves
- Slight or moderate changes
- Extreme changes

(2) Dimensional
- N – Negligible change; under 1 percent
- D – Dissolves
- M – Moderate changes
- E – Extreme changes

[illegible] Materials From Impregnated at Service Conditions

Polystyrene			Vinyl Chloride–Acetate Copolymer				Cellulose Acetate				Cellulose Nitrate				Ethyl Cellulose			
(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
+N	N	N	+N	–N	N	N	+N	+N	A	Y	+N	+N	N	Y	+E	+N	N	
+N	N	N	+N	+N	N	N	+M	+M	A	Y	+M	+N	N	Y	+M	+N	N	
+N	N	X	+N	–N	N	X	+E	+E	E	Z	–M	–M	A	Y	+M	+N	N	
+N	N	X	+N	N	N	N	+M	+M	A	Y	+M	–N	A	X	+M	+N	N	
+N	N	N	N	N	N	N	+E	+E	D	Z	D	D	E	E	D	D	D	Z
+N	N	N	+N	N	N	N	+E	+E	D	E	D	D	E	E	D	D	E	Z
D	D	Z	D	D	D	Z	D	D	D	Z	D	D	D	E	D	D	D	E
D	D	Z	D	D	D	Z	D	D	D	E	D	D	D	E	D	D	D	E
D	D	Z	D	D	D	Z	+E	+E	E	Z	+E	+E	E	Y	D	D	D	E
D	D	Z	+N	–N	N	N	+M	+N	N	N	+M	+N	N	N	D	D	D	E
D	D	Z	+E	+E	E	Z	+M	+M	N	Y	+M	+E	D	Y	D	D	D	E
D	E	Z	–N	–N	N		–N	+N	N		+N	–N	N		+E	+E	E	
+N	N		+N	–N	N		+M	+N	N		+M	+N	N		+M	+N	N	
+N	N		+N	+N	N		+M	+M	N		+M	+N	N		+M	+N	N	
–N	N	N	+N	+N	N	N	E	E	E	E	–M	+M	N	X	+M	+N	N	
+N	N	N	+N	–N	N	N	+E	+E	E	Z	+M	+M	N	Y	+M	+N	N	
–N	N		+N	–N	N		+M	+M	A		+M	+N	N		+M	+N	N	
+N	N		+N	–N	N		+M	+N	N		+M	+N	N		E	E	E	
+N	C		+N	N	N		+M	+E	A		–M	+N	A		+M	+N	N	
+N	N		+N	–N	N		+M	+M	A		+M	+N	N		+M	+N	N	
–N	N		+N	–N	N		+M	+M	N		+M	+N	N		+M	+N	N	

(3) Appearance
N – Negligible change
Y – Discolored, dulled or yellowed
A – Attacked and roughened
D – Dissolved

(4) Strength
N – Negligible loss
Z – 0 to 25 percent loss
Y – 25 to 50 percent loss
X – 50 to 75 percent loss

3. Reagents which have no apparent effect when tested individually may show marked effect when mixed or when applied successively.

4. The immersion time of 168 hours is comparatively short and frequently marks only the beginning of an action. Special cases and supplementary information to that presented in the table follow under the headings of the more common plastic materials.

Phenolics.

The chemical resistance of phenolics is complicated by the various types of fillers which are employed in molded and laminated parts. The filler will not improve the chemical resistance of the resin but rather will detract from the resistance of the compound by absorbing the reagent or by having poor resistance in itself. Thus, fabric-filled molded phenolic and laminated phenolic will be more susceptible to the action of chemical reagents because of absorption of the reagent into the fibers of the filler. Inorganic fillers with low water absorption, such as asbestos, therefore, give maximum protection to the resin and to the molded part. Those phenolic molding compounds which are classed as chemical resistant are generally filled with either asbestos, graphite or mica. These special formulations show improvement over the general-purpose material evaluated in the table to the extent that the most severe reagent, 10 per cent sodium hydroxide, causes only a 5 per cent increase in weight, a 5 per cent swelling and a 50 per cent drop in strength after six months of exposure. Other reagents showed little effect other than surface attack.

Most phenolic molding compounds are made by a two-stage process employing the addition of hexamethylenetramine, known as hexa, in an intermediary step. This agent is responsible for the liberation of ammonia in the molded phenolic material. Under unfavorable conditions, such as high heat and humidity, this ammonia is liberated, often with harmful effects in respect to odor and corrosion. Typical applications in which this trouble has been experienced are molded instrument cases, refrigerator controls and housings for delicate radio apparatus. This source of trouble can be eliminated by using a phenolic resin made in one stage which does not use any hexa. A "wet mix" compound is a material of this type. Laminating varnishes are also one-stage resins and are ammonia free.

Other than this difference in resins, phenolic laminated materials respond much the same as molded phenolics to chemical reagents. Laminating resins are slower to polymerize and test samples may show an appreciable attack by solvents such as alcohol and acetone. Strong acids and alkalies will attack the laminate and destroy its appearance and strength. Many corrosive and oxidizing reagents will attack the surface of the material without seriously impairing its mechanical strength. The use of sheet material in pumps, bearings, plating barrels, gaskets, rayon buckets and other parts in contact with chemicals has been tried successfully. In some instances, applications are made when chemical attack is obvious, but the useful life of the material is better than any other.

Urea and Melamine.

Ureas are frequently used for closures, tableware, soap dispensers, buttons and packaging for cosmetics and drugs. As such, it is subject to chemical action and particularly to the repeated use of soap and water. Properly molded urea parts are not affected by immersion in water and in mild cleaning agents, but they will swell and check if improperly molded. If continually immersed, urea will approach 5 per cent in water absorption and will swell appreciably. This swelling will cause cracking in heavy sections and in poorly designed pieces. Urea is considered particularly good in its resistance to greases, organic solvents and oils.

Available information on the chemical resistance of melamine indicates that it is completely resistant to tap water, soap solutions, methanol, butyl Cellosolve, ethylene dichloride, acetone, glycerine, xylene, 10 per cent citric acid and 10 per cent caustic soda. Concentrated ammonia will cause discoloration

and 40 per cent sulfuric acid causes bad discoloration and attack. Melamine shows more resistance to dilute acids and alkalies and is less affected by boiling water than urea.

Polystyrene.

Polystyrene has the distinction of being one of the best plastics for all-around acid and alkali resistance. Concentrated sulfuric and nitric acid cause it to lose 20 per cent of its strength, but this is the most severe effect of attack by the common acids and alkalies. Its ultimate water absorption over long periods of time is practically nil. Common solvents, in order of rapidity of action, are acetone, chloroform, methyl ethyl ketone, toluene, ethyl acetate, benzene and carbon tetrachloride. Applications of polystyrene include bottles and closures for acids, battery cases and grid clamps, refrigerator trays and bezels, liquor dispensers and perfume and cosmetic packages.

Methacrylate.

The low concentrations of acids in the test reagents listed in the table are rather misleading in the case of methyl methacrylate. This material loses its strength and appearance when contacting concentrations above 40 per cent sulfuric, 10 per cent nitric, 50 per cent acetic acid and 25 per cent sodium hydroxide. It is also slightly attacked by gasoline which contains benzol or tetraethyl lead. These limitations do not affect its most widely used applications, however, and it turns in a good performance in such parts as dentures, brushes, electroplating masks and cosmetic containers which require moderate chemical resistance.

Cellulose Derivatives.

Cellulose acetate is resistant to the aliphatic and aromatic hydrocarbons, and most of its chemical applications stem from this property. It is used for oil cans, tool and valve handles and for items requiring little solvent resistance. Cellulose acetate butyrate has slightly greater chemical resistance because of its decreased water absorption. This is also true of cellulose nitrate, which has comparatively good water resistance. Ethyl cellulose is noted more for its ability to be dissolved than for its solvent resistance. It is readily dissolved in the alcohols, esters, ethers, ketones, and the chlorinated and aromatic hydrocarbons to form various lacquers, coatings and cements. Its acid and alkali resistance lends it to normal applications such as tubing, wire insulation, packages and coatings. One of the outstanding wartime applications of ethyl cellulose has been the molding of Army canteens.

Vinyls.

The copolymer of vinyl chloride and vinyl acetate has a resistance to acids and alkalies which is comparable to that of polystyrene. In addition, it is soluble only in ketones, esters, polyethers and the chlorinated hydrocarbons. This combination lends itself to a wide variety of applications, typical of which are molded insecticide sprayers, gasket material, extruded tubing and coatings and masking films for electroplating. Polyvinyl chloride, which constitutes up to 95 per cent of the copolymer, is also recognized to have superior chemical resistance by itself. It is especially adapted to flexible wire coverings, calendered fabrics, extruded tubing and coatings that must be resistant to weathering and other forms of attack.

Polyvinyl alcohol is unique in being water soluble and at the same time possessing extremely good resistance to oils, fats, greases and most organic solvents. As a film, molding or extrusion it has been used for gloves, aprons, tubing and gaskets.

Vinylidene Chloride.

Practically the only reagents in a widely assorted group, including those listed in the table, that are considered unsuitable for or detrimental to vinylidene chloride, or Saran, are ammonium hydroxide, dioxane, bromine and chlorine water, ethyl dichloride, diethyl ether and O-dichlorobenzene. Saran

is extensively used for extruded tubing and pipe, and as such must be carefully investigated for possible corrosive chemical effects. Other applications are spray-gun handles, valve seats and nozzle tips, spinnerette couplings rollers and guides for rayon manufacture.

NYLON.

Nylon is resistant to ordinary solvents, such as esters, ketones and alcohols, and to alkalies and weak acids. It is attacked by phenol, formic acid and concentrated mineral acids. Its moisture resistance is only fair and molded specimens exhibit a comparatively high swelling. Applications pertinent for their chemical resistance are paint brushes, surgical sutures and Zippers.

COLD-MOLDED NON-REFRACTORY.

Cold-molded materials of the non-refractory class are generally made of asbestos filler and a bituminous or a phenolic-resin binder. In general, the bituminous binder is resistant to acids and alkalies where the phenolic is not, and the phenolic is resistant to common organic solvents where the bituminous is not. The chemical resistance of these materials is usually adequate for the usual applications of cold-molded materials. If the application is unusual a further check should be made.

MOISTURE ABSORPTION.

Water is the most important single reagent to consider in the test for chemical resistance. It occurs most frequently and is also the medium of solution for many of the other reagents.

Moisture absorption is not a chemical reaction. Aside from remote instances, the possibility of water entering into chemical reaction with the plastic material can be dismissed. Likewise, there are only a few clear-cut cases in which water dissolves the plastic or one of its components. Polyvinyl alcohol is water soluble and the softer types of cellulose acetate have water-soluble constituents.

The principal effect of water is to diffuse through the material by capillary action. This action may carry with it a chemical reagent that attacks the plastic, leach out a soluble constituent, promote the growth of fungi,or cause swelling. Tests for 24-hour or even 7-day immersions are long enough to indicate only a trend in moisture absorption. Most plastic materials do not reach their saturation equilibrium until after 18 to 24 months of immersion. Exposure to water vapor instead of immersion requires 10 to 50 per cent longer to reach saturation. Since most plastics applications are not subject to such severe wetting, their true moisture absorption must be more or less estimated from the relative wetting and drying times in their service cycle. Long-time immersion tests show that various materials reach saturation at the following values:

Polystyrene	negligible
Vinyl Copolymer	0.2 per cent
Methacrylate	1.5 per cent
Ethyl Cellulose	4.5 per cent
Urea	5.5 per cent
Phenolic, general-purpose	7.0 per cent
Casein	very high

AGING AND WEATHERING.

The most common types of action to which a plastic part is subject in service are:

1. Absorption of moisture and subsequent drying.

2. Effect of corrosive elements usually brought on by wetting of the surface of the part.

3. Oxidation of resin and filler which is continual and is accelerated by heat, moisture or sunlight.

4. Mechanical stress brought about by moisture absorption, freezing or thermal expansion.

5. Evaporation or leaching out of volatile or soluble constituents, such as plasticizers or lubricants.

6. Discoloration and fading from exposure to ultraviolet light and sunlight.

Phenolics in general withstand these types of deterioration very well. The most troublesome is usually warping and cracking brought about by uneven moisture absorption and uneven exposure to heat. The darker colors available in phenolics are not appreciably affected by weathering. Loss in appearance of parts generally results from swelling of surface fibers and loss of polish.

The design and manufacture of parts from ureas is more critical for satisfactory resistance to aging and weathering. Heavy sections are susceptible to cracking when wetted and dried. Sunlight tends to fade the lighter colors and the pastels, and severe ultraviolet will yellow the white urea resin. Thin, well-cured sections retain their appearance and surface finish in outdoor applications.

Highly plasticized materials, such as cellulose acetate and some of the vinyl pompounds, suffer in aging because of the loss of volatile plasticizers. The cesult is a gradual embrittlement of the plastic material. Samples of transrarent cellulose acetate exposed for one year out-of-doors averaged a shrinkage of 2 per cent and an increase in haze value of from 6 per cent up to 15 per cent.

Taste and Odor Characteristics.

Many plastics will impart or have objectionable odors and tastes when used in contact with foods, beverages, drugs or cosmetics. Recognition and evaluation of this characteristic is frequently difficult. Odors can be accentuated by placing the plastic in a jar of hot water and sealing. After a short interval the odor should be distinguishable when the jar is opened. The effect on foods can sometimes be detected by the taste of sweet butter which has been in contact with the plastic for a short time. Phenolic closures are known to contaminate the odor and taste of alcoholic liquors. A bromination test developed to detect this tendency determines the amount of free phenol and ammonia in the phenolic. The chemical determination compares favorably with standard odor-taste tests. Very little quantitative data are available on this characteristic largely because of lack of a suitable test.

MAGNESIUM.—This short description of magnesium production and utilization is reprinted from the Nautical Gazette, November, 1944.

How many times does six go into five hundred? Divide it out and you begin to get some idea of what the war has done to or for the magnesium industry. For the six million pounds of magnesium which America was producing annually before the present war has doubled and trebled and quadrupled and so on until now it looks like a total of 500,000,000 pounds of the stuff will be turned out during 1944. In short, you can't take magnesium lightly.

Half a billion pounds is a lot of magnesium. Where does it all come from and who makes it? The major process produces magnesium by the electrolytic reduction of fused magnesium chloride. Brine, sea water, magnesium salts and magnesite are the raw materials from which this magnesium chloride is produced. The other processes depend on the direct reduction of magnesium, one using carbon and the other employing ferrosilicon as the reducing agent. There are fifteen plants producing magnesium, operated by eleven companies.

Those six million pounds which were the pre-war production were more than enough for the needs of that time but they fell far short of military demands of today. But the greatly expanded production now even permits the release of magnesium for civilian needs.

Aircraft and incendiary bombs absorb about 76 per cent of the total production of magnesium. Something between 85 and 90 per cent of the magnesium

used in aircraft is in the form of sand and permanent mold castings, most of them used for engine parts and wheels. By using the metal in landing wheels it has been possible to save from 50 to 150 pounds' weight per plane on medium and heavy models. The metal's sturdy resistance to shock and to landing stresses excellently fit it for this demanding service. In all of its various forms—castings, sheet, extruded shapes, tubing and even forgings—magnesium foots up to about 1600 pounds on a heavy bomber, 800 pounds on a light bomber and 500 pounds on a fighter, and these quantities are all on the increase.

But extensive though the uses of magnesium are in aircraft, it is startling to discover that about 41 per cent of the country's output of this metal goes into incendiary bombs and other pyrotechnic uses, such as flares and tracer bullets. The greatest single use for magnesium is the incendiary bomb. This trinket consists of a magnesium casting weighing slightly more than a pound and containing thermite, a mixture of aluminum powder and iron oxide. The magnesium casting not only provides a light-weight case but also adds to the intensity of the fire when the thermite reaction has become hot enough to ignite the metal.

But important though magnesium is in wartime, its peacetime uses are very extensive. The metal possesses a combination of properties which make it especially adaptable to a wide variety of applications. Its most striking quality is its lightness, being only 23 per cent that of iron and 64 per cent that of aluminum. Wherever there is mass in motion, lightness may lead to reduced operating costs, better performance and more payload. In designs where there is a limitation on weight the use of light materials permits the specification of thicker and stiffer sections without a weight penalty. Thus comparisons of the cost of magnesium and competitive metals should take the lightness of magnesium into account because on a volume basis it may mean a lower material cost.

Like most metals, magnesium is best when laced with something else, being rather weak in its pure state. When alloyed with other metals its strength is greatly increased. Because magnesium alloys have excellent strength-weight ratios they have many structural applications. It is imperative, however, to consider temperature factors if much heat is involved. The use of magnesium alloys for structural purposes at temperatures in excess of 400 degrees F. is not recommended. At subnormal temperatures, however, magnesium alloys undergo only negligible changes of strength.

Magnesium alloys are adaptable to modern processes of fabrication and assembly and are available in most commercial forms. They are cast in sand, permanent and semi-permanent molds and in die-casting machines. In wrought form they are rolled into sheet and plate, extruded into rod, bar and wire, structural shapes, molding and tubing, and are forged into hammer and press jobs. Other forms include rolled strip, ribbon and alloys for deoxidizing purposes. These various forms are available in a wide assortment of sizes, while the castings may be produced in weights from a fraction of an ounce to well over 700 pounds.

Most of the usual processing methods lend themselves to magnesium alloys. They may be drilled and machined fast and with a smooth finish and they can be torch-welded or joined by resistance or electric spot welding. Riveting can be done by using aluminum alloy rivets. In general salt water and salt spray are corrosive to magnesium and unless it is known that the conditions of service are not detrimental to magnesium it is advisable to protect the magnesium parts with a suitable chemical coating followed by painting. The metal is non-toxic and non-sparking. Weight for weight it is more expensive than the other common commercial metals. But when volume is taken into the picture magnesium looms up as having a price advantage over its competitors because of its lightness.

The total number of magnesium fabricators has multiplied about 25 times since 1939. In that year there were only four major fabricators, of which the American Magnesium Corp. was the largest. Today the number of fabricators has increased to nearly a hundred. About 67 of them are producing sand castings, permanent mold castings, die castings and extrusions for engineering

purposes. Magnesium powder is produced by eighteen of them and another fourteen are making incendiary bomb casings. Despite the increased number of concerns now engaged in magnesium fabrication, the American Magnesium Corp. still rates as largest.

A wholly-owned subsidiary of the Aluminum Company of America, the American Magnesium has been engaged in an almost constant expansion of its plant since the war clouds began to gather in 1939. Its operations include plants at Cleveland, Buffalo, Bridgeport. These factories are backed by an extensive development program for the evolving of new and improved processes and alloys. This is conducted by the American Magnesium's scientists in collaboration with the Alcoa research laboratories.

ASSOCIATION NOTES

Officers for 1945.

The following have been elected officers of the Society for the calendar year 1945:

President:

Rear Admiral E. W. Mills, U. S. Navy.

Secretary-Treasurer:

Commander Robert T. Sutherland, Jr., U. S. Navy.

Members of Council:

Rear Admiral E. W. Mills, U. S. Navy.
Rear Admiral A. M. Charlton, U. S. Navy.
Rear Admiral F. J. Wille, U. S. Navy.
Captain P. F. Lee, U. S. Navy.
Captain H. C. Sexton, U. S. Navy.
Commander Robert T. Sutherland, Jr., U. S. Navy.
Commander H. E. Davis, U. S. Coast Guard.
Lieut. Commander E. G. Kintner, U. S. Naval Reserve.
Mr. Fred Sells.
Mr. W. H. Bailey.
Mr. G. B. Warren.

Rules for Prize Article by Naval Reserve Officer.

The following rules have been adopted by the Council of the Society to govern submission of articles in the contest authorized at the Annual Meeting of the Society on 3 October, 1944, and announced in the November, 1944 issue of the Journal:

(1) A prize of $500.00 will be awarded for the best article submitted on the subject "Engineering in the Navy as Seen by an Active Reserve Officer" if any is considered by the Council to be worthy of that award. Additional prizes of $250.00 and $100.00, respectively, may also be awarded for the two next best papers.

(2) All reserve officers of the U. S. Navy or U. S. Coast Guard who have served on active duty at least six (6) months during the calendar year 1944 or 1945 are eligible to compete, whether or not they are members of the Society.

(3) Articles shall be typewritten, double-spaced and submitted in triplicate. All illustrations shall be reproduceable. They shall bear the statement that they are offered in competition for the prize.

(4) No limitation is placed on the length of articles, but it is preferred that they shall not exceed 8000 words.

(5) Every effort shall be made to have the articles reach the Secretary-Treasurer by 31 December, 1945. No manuscript will be considered that arrives later than 15 January, 1946.

(6) Any entry may be published either before or after award if the Council so desires. All articles published will be paid for at the usual rates, regardless of prize awards.

(7) Contest winners will be rewarded as soon as possible after 31 December, 1945, and winners will be announced in the May, 1946, issue of the JOURNAL.

CANCELLATION OF ANNUAL BANQUET.

Plans for holding a banquet on April 20, 1945, at the Statler Hotel in Washington, previously announced, have been cancelled. This action was taken with the utmost reluctance and keenest disappointment following direct consultation with the Office of War Mobilization relative to its expressed policy that, because of transportation and hotel conditions, no gatherings of more than fifty persons should be held after February 1, 1946. The Council considered cancellation imperative, especially in view of the very close, although not official, relations of the Society with our Federal Government. It is earnestly hoped that at a not too distant date, it may be possible to resume these delightful events.

MEMBERSHIP.

The following have been admitted to membership since the publication of the November, 1944, JOURNAL:

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